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THE MOUNT LYELL MINING FIELD,

TASMANIA.

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THE

MOUNT LYELL MINING FIELD

TASMANIA.

WITH SOME ACCOUNT OF THE GEOLOGY

OF

OTHER PYRITIC ORE BODIES.

BY

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AND

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AUSTRALASIAN INSTITUTE OF MINING ENGINEERS.

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HARVARD UNIVERSITY
MINING AND METALLURGICAL
LABORATORY
JAN 20, 1922
GIFT
MISS SUSAN T. CUSHING

TO

J. H. MacFARLAND,

THE MASTER OF ORMOND.

AS A TRIBUTE OF RESPECT TO HIS DEVOTED SERVICE

TO VICTORIAN EDUCATION.

PREFACE.

AMONG the necessary consequences of successful mining is the destruction of the evidence as to the origin and relations of the ore deposits. Unless the mines are described, while they are being worked, all chance of accurate knowledge of their geology is lost; and clues, by which a later generation of miners might follow the lode tracks to greater depths, are destroyed for ever. I accordingly trust that the Geological School of the Melbourne University will take some share in the description of those Australian mining fields which have not yet been monographed by the State Surveys; and I hope that the following account of the Mount Lyell Field will be only the first of a series from the Geological School of the University.

Recognition of the importance of geology, as a guide to mining, seems to me to be rapidly growing in Australia. It is becoming more widely understood that mining geology is not a batch of speculative hypotheses, but a collection of verified and systematically arranged facts, as to the relations of ore deposits. This branch of geology accordingly enables miners to distinguish true from false analogies between different mining fields, and thus to save deplorable waste of money in development of the mines.

In addition to the men, to whom I have expressed my indebtedness on page 3, I have to thank Mr. A. S. Kenyon for his careful help in passing this book through the press.

J. W. GREGORY.

THE UNIVERSITY,
MELBOURNE,
30th August, 1904.

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PART I.

THE MOUNT LYELL MINING FIELD.

CHAPTER I.—INTRODUCTION.

GREAT masses of pyritic minerals include some of the most valuable and interesting of known ore deposits. These great ore bodies are of high economic importance, for, though their intrinsic value is low, their vast bulk enables them to be often worked by simple quarrying; they are full of scientific interest, from the many problems connected with their formation; and they are famous historically, as, owing to the ease with which the copper can usually be extracted from them, they have yielded supplies of that metal since pre-historic times.

The most famous of these pyritic masses occur at Rio Tinto and Tharsis, in south-western Spain, and at San Domingos, in south-eastern Portugal. The mines of that district have been worked from the earliest days at which men used metals, when the only mining tools used were of wood and stone. The pre-historic miners were followed by the Phœnicians, who from 1200 B.C. to 650 B.C obtained from the Rio Tinto district most of the copper with which smelted with Cornish tin, they made their bronze. Long after the fall of the Phœnicians, the Romans re-discovered the deposits and organized a mining industry, which maintained, on the copper fields, a population numbered by its millions; they worked the ores on such a scale that the slag has provided ballast for many miles of railway, without, it is said, any appreciable effect on the size of the heaps. On the expulsion of the Romans by the

Visigoths, the mines were again abandoned. After repeated vain efforts to work the mines profitably, a British company, in 1866, secured control of Rio Tinto, and once again made it one of the great copper mines of the world.

Pyritic masses such as those of Rio Tinto are well known in various parts of the world. They present promising fields of work; for their ores are unusually constant in range and composition; they have mostly proved persistent in depth, and the size of the ore bodies is colossal. These pyritic masses, however, generally consist of such low-grade ore that they may not be economically valuable. unless they occur in countries of cheap labour, in localities easy of access and near the big markets of the world. The great pyritic ore body of Mount Lyell, situated in the rank forests of the western Tasmanian highlands, has none of these advantages. It has to be worked with the high-priced labour of Australia; the mine is in a country with such a repellent climate that the conditions offered to workmen must present special attractions; it is so difficult of approach that costly and arduous engineering feats had to be accomplished before its development could be undertaken; and it is so far from the markets of the world that bye-products, elsewhere of great value, have had to run to waste.

The development of the Mount Lyell mine is one of the brightest stories in the annals of Australian mining. It reflects the highest credit on the Melbourne financiers who had the courage to undertake the task, and who, undaunted by obstacles, which would have been insuperable to weaker men, carried it through to a triumphant issue. They owe their success to their perseverance, to the administrative ability with which they secured efficiency without waste, and to the judgment with which they selected men of high scientific skill to conduct their operations. The credit of the successful issue of this great industrial achievement belongs to the directors of the Mount Lyell Mining and Railway Company, notably to the chairman, Mr. Bowes Kelly, the vice-chairman, Hon. William Knox, M.H.R., and Messrs. William Jamieson, J. C. Syme, and L. Tulloch, to the Company's early

operations being guided on wise lines by Mr. H. H. Schlapp, and to the combined administrative capacity and scientific skill of Mr. R. C. Sticht, the general manager of the Company.

The geology of the Mount Lyell mining field is less known than that of any other of the great pyritic mines of the world. Being interested in this type of ore deposits, and unable to get any very convincing account of the geological structure of the field, I prepared, shortly after my arrival in Australia, to go there for a fortnight's vacation, in the winter of 1900. But the appalling accounts given me by Melbourne friends of the winter climate of Mount Lyell, where I was assured that the average shower lasts three months, and geological work would probably be prevented by snow, induced me to postpone a visit till a more suitable season.

Accordingly, I gladly accepted a subsequent invitation to Mount Lyell, and during two visits, in January and May, 1903, I had the opportunity of a careful examination of the Mount Lyell mine, and a study of the geology of the surrounding country. I must express my thanks to the directors of the Mount Lyell Mining and Railway Company for the full opportunity of examining their mine and leases, and to all the officials of the company for their uniform kindness, and the instructive information which they generously gave me during these visits. I must especially thank Mr. R. C. Sticht, the general manager, and Mr. W. T. Batchelor, the engineer in charge of the company's mining operations, for their kind hospitality and help. I am further indebted to Mr. Sticht for having kindly read through the manuscript, and for many valuable suggestions in regard to it; also to Mr. Batchelor for an account of the North Lyell Mine. Mr. Batchelor gave me the benefit of his guidance and company in most of the excursions during my first visit, and he sent me a well-selected representative collection of the rocks of the district for preliminary study in Melbourne. I am indebted to Mr. G. F. Beardsley, then the chief metallurgist of the company, for various analyses made under his supervision; to Mr. H. Clark, the engineer of supplies, and Mr. E. Carus Driffield, the superintendent of the railway, for help in travelling through the field, and for transport. Thanks to the

help received from the company's officers, I was able to make a far more detailed examination of the field than would otherwise have been possible in the time available to me; and I was able to see so much of the country that the short report I had originally intended has increased to the length at which separate publication seems advisable. For the opportunity of comparing the Mount Lyell rocks with those of the corresponding series at Zeehan I am indebted to Mr. Reed, who kindly arranged for me to inspect the collection at the Zeehan School of Mines. Mr. A. H. Waller, late of the Tasmanian Geological Survey, gave me the benefit of his knowledge of the Zeehan and Dundas mining fields, and Mr. W. H. Twelvetrees, the Government Geologist of Tasmania, has kindly answered numerous questions. For help in consulting plans at Gormanston, for the determination of various altitudes, for some theodolite readings and rock specimens, I am indebted to Messrs. Beamish and Murray, of the Mount Lyell Company's mines office. I am also indebted to Mr. A. Mellor, the secretary of the company, for the opportunity of seeing the collection of plans and photographs of the field, and for much general information; and to my assistant, Mr. H. J. Grayson, of the Geological Laboratory of the Melbourne University, who has supplied the admirable microphotographs by which my account of the rocks is illustrated.

Mount Lyell is one of the mountains of the West Coast Range of Tasmania, and is in one of the least explored and least accessible regions of the island,* though it is situated only 18 miles from the best harbour on the inhospitable western coast. Mount Lyell forms part of that higher range of mountains which Tasman saw to the east-north-east of him when he first discovered Tasmania, on the 24th November, 1642. His expedition will ever be

* Thus R. P. Whitworth, in Bailliere's "Tasmanian Gazetteer," 1877, p. 137 says of the county of Montagu, in which Mount Lyell occurs:—"Little, next to nothing, is known of this county, further than that it consists of large heathy plains traversed by mountain ranges. The principal peak is called Mount Heemskirk."

remembered in connection with this region, thanks to the graceful action of Flinders, who, when surveying this coast in 1798, named the two nearer mountains referred to by Tasman after that explorer's vessels—the yacht *Heemskirk* and the flyboat *Zeehan*. Flinders might himself have seen Mount Lyell and the West Coast Range, but he tells us that as he sailed up the coast on 11th December, 1798, the country behind "the back ridge of woody hills" was covered by haze.* It was not until after 1822, when a convict settlement was established at Sarah Island (or Settlement Island), in Macquarie Harbour, that much special knowledge was obtained about this part of Tasmania. This site for the convict station was selected as the only approach to it was from the sea, and it was believed that the rough country behind Macquarie Harbour would prevent the convicts escaping to the settled districts of the island. Hence, according to Backhouse,† who visited the settlement in 1832, the prisoners were allowed a fair measure of personal liberty, as they felled timber in the woods, or built boats upon the island. But life at Macquarie Harbour was so distasteful that many of the prisoners risked the perils of the supposed impassable barrier; it was calculated that out of one series of 112 prisoners who escaped overland, 71 were lost in the bush or killed and eaten by their comrades. But in such abhorrence was this station held, that not even the known risks of a journey through the forests prevented further attempts at escape. According to Backhouse, the prisoners so hated Macquarie Harbour that murders were committed so that the murderer might get one last respite from its horrors, and the witnesses at the trial might get temporary removal to Hobart. A history of the penal settlement is given by T. G. Lempriere.‡ Some account of this settlement, and of the impenetrable nature of the country behind it, is contained in Marcus Clarke's famous novel "For the Term of his

* Flinders, M., "A Voyage to Terra Australis," vol. i., 1814, p. clxxv.

† Backhouse, James, "A Narrative of a Visit to the Australian Colonies," London, 1843, pp. 45–58.

‡ Lempriere, T. G., "Account of Macquarie Harbour," Tasmanian Journal Nat. Sci., &c., vol. i., 1842, pp. 359–75; vol. ii., 1846, pp. 17–31, 107–118, 200–208.

Natural Life." No effort was made to explore the wild maze of forest-clad ridges that lay behind the harbour, and after the abandonment of the convict settlement, because of its difficulty of approach, even the coast lands were again neglected.*

The first account of the country to the east of Macquarie Harbour is that of Calder,† who explored some of the area as far inland as Lake St. Clair, between November, 1840, and January, 1842.

Occasional expeditions crossed the country between the western coast and Hobart, such as that of Sir John Franklin in 1842, in which he achieved success after characteristic difficulties. Gould's expeditions of 1860 and 1862–3 appear to have been the first to reach the Mount Lyell mining field. Gould crossed it in 1860, when he traversed the Linda Valley, which he named the "Chamounix Valley," probably because he recognized the glacial origin of the hills at Gormanston. He also named Mounts Murchison, Sedgwick, Lyell, and Owen. He discovered gold in a few places, as at two and a half miles up the King River, and on the Franklin River, and he reported a rumour of its presence on Headquarters Island, in Macquarie Harbour. But apparently he found no trace of gold or copper on the Mount Lyell field itself.

Gould's explorations showed that the steep hill slope that lies behind the West Coast of Tasmania was the face of a plateau. Beyond the top of this face or "scarp" the plateau (a raised pene-plane) extends inland to the foot of the still higher central plateau. Both these plateaus have now been dissected by river action, and the country is now a maze of deep gorges and high ridges, so that the original plateau structure can only be recognized in a broad general view.‡ The whole region is covered with dense, rank forest, which is passable only with great

* Lempriere, T. G., *op. cit.*, vol. i., p. 370.

† Calder, J. C., "Some Account of the Country Lying Between Lake St. Clair and Macquarie Harbour," Tasmanian Journal Nat. Sci., &c., vol. iii., 1849, pp 415–429.

‡ Sketches showing this feature are given in Proc. Roy. Soc. Vict., vol. xvi. new series. (1903), pl. xx., xxi.

difficulty. The western plateau bears upon its surface a range of isolated rugged mountains, which Gould named after various distinguished geologists. It runs from north to south, and is now known as the West Coast Range;* it is separated from the central plateau by the valleys of the King and Murchison Rivers.

This country, with its dense forests of Huon pine and other valuable timbers, was slowly opened by woodmen felling timber; but little progress at settlement was attempted until 1877, when tin was discovered at Heemskirk. The first attempt to work the tin was, however, a failure. The country was again neglected, until the discovery of the silver-lead ores at Zeehan secured, in 1884, the first permanent settlement in this district. Subsequently the endeavour to determine the distribution of the gold found by Gould, and to trace it to its source, led to the discovery of the copper field of Mount Lyell.

The success of mining enterprise in this part of Tasmania marked a turning point in the history of the colony, which had been passing through a long period of stagnation and depression. It was only in 1873 that Anthony Trollope deplored that "it seems hard to say of a new colony, not yet 70 years old, that its short period of importance in the world is already gone, and that for the future it must exist—as many an old town and old country do exist—not exactly on the memory of the past, but on the relics which the past has left behind it."† The very year after Trollope's pessimistic prediction, its fulfilment was begun in a way that he did not expect; for Tasmania received the first contribution to its renewed era of prosperity, by the discovery of those relics which the far distant past had left in it—the rich ore deposits of its north-western mining fields.

* Who first used that name I cannot learn.

† Trollope, A., "Australia and New Zealand," 1876 (Aust. edit.), p. 335.

Chapter II.—The Situation of Mount Lyell.

The Mount Lyell mining field is on the main ridge of the Tasmanian West Coast Range. This range consists of a series of mountains of conglomerate, resting upon a base of schists, which are exposed in the valleys between the conglomerate masses. The Mount Lyell mine occurs on one of the saddles of the West Coast Range; it is on the ridge of schists that connects Mount Lyell to Mount Owen and separates the Queen River from the Linda River, both of which are tributaries of the King River. The Queen River runs from north to south, along the western foot of the West Coast Range. The Linda Valley runs from west to east in one of the transverse valleys cutting across the range. The Linda River joins the King River, which flows southwards along the eastern foot of the West Coast Range and cuts through it by a deep canyon, between Mount Huxley and Mount Jukes. The King River continues westward, is joined by the Queen River, and discharges into Macquarie Harbour.

The West Coast Range is situated from 20 to 25 miles from the western coast of Tasmania. The chief peaks, going from north to south, are Mounts Black, Murchison, Geikie, Tyndall, Sedgwick, Lyell, Owen, Huxley, Jukes, Darwin, and Sorell. These peaks all consist essentially of huge blocks of conglomerate, separated from one another by transverse valleys. The mountains and ridges crossing the heads of the intervening valleys form a continuous watershed, which is continuous from Mount Black to Macquarie Harbour, being broken only by the canyon of the King River. The Mount Lyell mines are situated along the ridge which runs from the western end of Mount Lyell to Mount Owen. The chief mines are on the eastern slopes of the ridge. The parent mine of the field, the Mount Lyell mine, is north of the town of Gormanston, and the North Mount Lyell mine is at the head of the Linda Valley, a mile

further to the north. The ore from the two chief mines is carried by an aerial line and an inclined rope haulage across the ridge to the smelting works at Queenstown, in the Queen Valley.

Queenstown is connected by a railway belonging to the Mount Lyell Mining and Railway Company to Strahan. The steep ridge on the right bank of the King River is crossed by a line on the Abt system.

Westward from the foot of the West Coast Range an extensive and deeply-dissected plateau stretches to the coast, near which it descends steeply to the sea level. To the east of the West Coast Range, beyond the valleys of the King River and the Murchison River, are the foothills and outliers of the great central plateau of Tasmania.

The country around the Mount Lyell mines was originally covered by dense forest, and abundant timber for mining purposes is still available. Owing to the heavy rainfall, water is plentiful, and the lakes to the north of the mining field can be utilized, whenever desired, for motive power.

Chapter III.—The Geology of North-Western Tasmania.

North-western Tasmania consists of a foundation of schistose rocks, which, though often regarded as Silurian, are older than the oldest known fossiliferous rocks of the country. These ancient rocks, which are probably Archean in age, include felsitic, talcose, and micaceous schists, forming a belt which trends north and south along the line of the West Coast Range. The schists are exposed at intervals on both sides of the Range, but occur mainly to the east. Some pre-Cambrian quartzites have been recorded from Port Davey, on the western coast, but their age, Mr. W. H. Twelvetrees, the Government Geologist of Tasmania, tells me, is a matter only of tradition. More certain outcrops of the Archean foundation occur below the central plateau of Tasmania, as in the hornblendic gneisses in the upper valley of the Forth River, and, further north, the mica schists of the Dove River may belong to the same rock group. Some Cambrian beds rest on the eastern flanks of the Archean rocks between the Mersey and Don Rivers, both of which flow into Bass Strait about 30 miles to the east of Emu Bay. On both sides of the main Archean ridge are broad areas composed of slates, sandstones and limestones. The sandstones, which are regarded as the lowest members of this series, occur on the Gordon River near Macquarie Harbour. They are accepted by Mr. Robert Etheridge as Lower Silurian (Ordovician), but the palæontological evidence is somewhat inconclusive. The limestones at Zeehan are of true, or Upper, Silurian age; we may therefore conclude that the lower Palæozoic rocks beside the West Coast Range are partly Silurian and probably partly Ordovician in age. Some poorly-preserved graptolites have been recorded 10 miles from Strahan, on the Mount Lyell road, and from the Ring River on the Dundas railway;* but the rich

* Hall, T. S., "Evidence of Graptolites in Tasmania," Rep. Sec. Mines, Tasmania, 1901–2 (1902), pp. 170, 171.

Ordovician graptolitic fauna of Victoria is still unrepresented in Tasmania. This fact raises doubt as to the existence of extensive Ordovician beds in that island; but as the lower Palæozoic rocks of north-western Tasmania occur in continuation of the line of strike of the chief Ordovician belt of Victoria, it is not improbable that they will prove to belong in part to the same system.

Above the Silurian and the probable Ordovician rocks are great banks of conglomerate; they form the Dial Range to the west of Emu Bay, and are continued southward in great blocks, forming the mountains of the West Coast Range, extending from Mount Black and Mount Murchison through Mounts Geikie, Tyndall, Sedgwick, Lyell, Owen, Huxley, Jukes, and Sorell to Macquarie Harbour. After the deposition of the conglomerates there followed great intrusions and outflows of igneous rocks, represented by the granites of the Heemskirk Range and the acid lavas and dykes of the same district.

After the intrusion of these igneous rocks there is a long gap in the geological records in the north-western mining fields, Tasmania; for the Carboniferous rocks, which are so widely distributed in the eastern and central parts of the island, and also outcrop on the northern coast, are barely represented. There is also little or none of the Mesozoic diabase, which, according to Johnston's sketch map, forms the surface of the Central Plateau of Tasmania; but the distribution of the diabase appears to be less regular than is represented on that map, and it may consist, as Mr. Stephens suggests, of a series of separate laccolitic intrusions. In the lower Cainozoic period, basalt flows were discharged down some of the northern valleys, and form the cap of the Surrey Hills; while limburgite dykes of the same date are exposed in places, as south of Burnie. These Cainozoic basalts project out to sea on the northern coast; they occur there at intervals from Cape Grim, the north-western corner of Tasmania, eastward beyond the mouth of the Tamar.

The middle Cainozoic in north-western Tasmania was probably a period of depression, during which the country was planed down into a series of pene-planes, above which the granitic hills and the West

Coast Range stood up like islands. There are three main divisions of these planes—the North-Western, Western, and Henty pene-planes; the last runs inland to the foot of the West Coast Range at Mount Lyell.

After the formation of the pene-planes the Tasmanian highlands were snow-clad, and an extensive series of glaciers flowed down the chief valleys to the west and north-west. The glacial deposits are widely distributed in the Mount Lyell district, and include the moraine upon which stands the town of Gormanston, and some of the beds first worked for alluvial yield.*

* Some account of the glacial deposits of this district and reference to the literature are given in the following paper :—Gregory, J. W., "A Contribution to the Glacial Geology of Tasmania," Quart. Jour. Geol. Soc., vol. lx., 1904, pp. 37–53, pl. vii. and viii.

Chapter IV.—The Mining History of Mount Lyell.

NOTES ON THE EARLY MINING HISTORY OF MOUNT LYELL.

By W. H. Taylour.*

"The mining history of the Mount Lyell field dates from the close of the year 1881, when Conrad Lynch landed at Safety or Farm Cove, near Kelly's Basin, in Macquarie Harbour, with instructions to prospect for gold in the vicinity of the Frenchman's Cap Mountain and the West Coast Range generally. He was the leader of a well-organized party, which was sent from Hobart by an association of professional and business men, afterwards called 'The King River Prospecting and Gold Mining Association No Liability.' Thomas Currie was second in command. Lynch, with a section of the party, travelled northwards from Farm Cove, skirting the foothills of Mount Sorell, towards the King River, whilst Currie, with the rest of the men, went north-easterly along the southern foothills of Mount Darwin towards the Frenchman's Cap. Not meeting with much encouragement, Currie retraced his steps and eventually rejoined Lynch. They crossed the King River, near its confluence with the Queen River, and in the valley of the latter they obtained small prospects of gold. This valley was densely timbered and covered with a tangled scrub, necessitating the party cutting their way through. They followed the Queen for about five miles, and then branched off at a creek coming from the east-north-east. In the bed of this creek, appropriately called after Lynch, payable gold, of a ragged reefy nature, was struck. A reward claim was pegged out, and Lynch returned to Hobart to report the discovery, which caused intense excitement and induced a small rush to the scene of the new find.

"Lynch was again fitted out by his association, and upon his return prospecting operations were resumed with much energy. He had been directed to endeavour to discover the reef from which the gold was assumed to have been shed. Early in 1883, on the reward claim, which is known as the King River Mine, he unearthed a bonanza. It was a pocket of quartz weighing 112 lb., which was treated at the Technical Museum in Melbourne by the late Mr. Cosmo Newbery, and yielded gold to the net value of £830 17s. 9d. This attracted a large number of miners to the vicinity, most of them coming from the poor alluvial goldfield on the Pieman and

* For the following account of the early history of Mount Lyell I am indebted to the kindness of Mr. Sticht, who asked Mr. Taylour, of the Mount Lyell Company's office, to prepare this account. Mr. Taylour was the first secretary of the Town Board of Queenstown.

from the declining Heemskirk tin-fields. Numerous leases were acquired in the immediate neighbourhood and further afield, and during the customary period of excitement companies were floated to work them. Fair parcels of alluvial gold were won from the surrounding creeks and gullies. Some promising-looking reefs were also located, notably the Princess (across the Queen River from Lynch's Creek), the Macquarie (nearer to Strahan), and the Madame Howard (on Howard's Plains, close to Queenstown); but although rich specimens were obtained, the bulk of the ore proved barren, or at least too poor to treat profitably. The gold in the quartz was very patchy. Considerable sums of money were expended upon the transport and erection of batteries, some of which are still to be seen on the almost deserted claims. The King River Prospecting Association alone spent nearly £20,000, the total gold recovered being of the value of £3,345 only.

"Among the miners who came from Heemskirk were William and Michael M'Donough, familiarly known as 'the Cooney Brothers,' and Johannes Stefanus Karlson, whose name is now associated with 'Karlson's Flat,' on the North Lyell spur. They had been prospecting on Howard's Plains with indifferent results, so they decided to make for new ground in the foothills of Mounts Owen and Lyell. In November, 1883, they started from their camp on the Plains with light loads, containing about a week's provisions. The first day out they crossed the Queen River near the present Reduction Works, and climbed over the spur connecting Mounts Owen and Lyell, following an old route supposed to have been Gould's, and not long before traversed by Currie and also by T. B. Moore and his brother James. In fact, the Moores were then prospecting on the western fall of this spur, and directed Karlson and mates to the track. That night they camped in a gully on the ridge above the present workings of the South Lyell Company, and next morning walked over the Mount Lyell Company's parent leases, passing close to the famous 'Iron Blow,' until they reached the upper portion of the Linda Valley (then charted 'Chamounix,' so called by Gould), near a waterfall on the old King Lyell Company's ground. A little prospecting soon revealed the presence of gold, and three men's ground was pegged off. The party soon afterwards returned to Howard's Plains for their tents, tools, and the balance of their stores, and lost no time in again reaching the location of their claims. Several other miners accompanied them, and it was not long before the Linda Valley was a fairly busy scene. Whilst Karlson was pitching camp on the hill above their alluvial claims, Bill McDonough went further up the steep incline to examine a massive outcrop ('The Blow'), and having pulled up some button-grass he shook the attached soil into his dish and panned off an excellent prospect. The party lost no time in further prospecting the hill, and so satisfied were they with the results that they posted a notice

for a prospecting area of 50 acres, in the centre of which was 'The Blow.' They were of opinion that this huge outcrop was the capping of the source of the gold found in the valley

"Having secured the prospecting area in Bill McDonough's name, F. O. Henry, then the only storekeeper south of Heemskirk, whose store was located at Old Strahan, about two miles by water from the present township, was given a tenth interest therein. Troubles now began, as a consequence of the lack of that cohesion, which is essential to the success of mateship. Mutual distrust appeared to stifle the spirit of reasonableness that had hitherto prevailed. Very little gold was being obtained, and Mick McDonough was behind with his food bill. Bill McDonough was frequently away, and during one of his absences, and whilst Karlson was at Trial Harbour securing water rights for sluicing operations on the Blow, M. McDonough, who was scared by an attempt to jump part of the prospecting area, admitted William Dixon as a member of the party. Dixon at the time was packing stores for some of the miners. Shortly afterwards, about April, 1884, James Crotty, who had been fossicking on the Pieman, and subsequently prospecting up the Gordon River, appeared on the scene. He was met on the track from Strahan by M. McDonough, and accompanied him to the Blow. Crotty was evidently pleased with the prospects, for within a few days after his advent he purchased M. McDonough's interest, the consideration being that he took over the latter's indebtedness for stores to F. O. Henry. Bill McDonough dropped out before long, and his interest somehow became Dixon's. The mutual distrust now became intensified, and bickerings were the order of the day, However, a good deal of prospecting was done on the area, and the sulphides tapped over a considerable distance.

"During the Christmas holidays of 1885 there was a sort of *modus vivendi*. It was agreed that a syndicate of 20 shares be formed. P. E. Karlson and K. O. Karlson (brothers of S. Karlson), who were in business at Trial Harbour, the inlet for supplies for the Heemskirk mines, were admitted as interest holders, on condition that they paid for the stores whilst water was brought on to the Blow for sluicing by S. Karlson, Crotty, and Dixon. Of the 20 shares, the three Karlsons, Crotty, and Dixon were to have three each, the remaining five to be allotted to F. O. Henry, who already had a tenth interest, equal to two shares in the new arrangement. Much against the wish of S. Karlson, who was watching his brothers' interests as well as his own, it was decided to engage Tom Strong, a whilom mate of Crotty's at Waratah, as mine manager. He, accompanied by a man named Carroll. a resident on the North-West Coast, arrived on the field about the end of January, 1886, and assumed control. Prior to his coming, S. Karlson and party had, with the aid of a screwjack, displaced large masses of

boulders from the outcrop to prepare a face for sluicing. Strong, however, preferred to work further down the hill, and as funds were consumed and little gold was being won, calls had to be made. Troubles began to accumulate, and eventually the Karlsons sold six of their nine shares to Carroll for £250. They had intended keeping the remaining three shares, but as Steve Karlson became more dissatisfied day after day with the manner in which Strong was working the area, he finally sold the last of his and his brothers' interest for £120, in June, 1886. Here the reign of the discoverers of the Blow ceased. The face that had been prepared for sluicing was now operated upon with success, and a parcel of gossan sent to the Bendigo School of Mines yielded on assay 15 ozs. of gold per ton. An equal interest to that which Karlson had sold for £120 a few weeks previously was now sold by Dixon to Mr. R. Powell, of Devonport, for £12,000. It should be mentioned that a battery had been erected on the area, with 10 head of stamps, and that although parcels of the pyrites had been sent by Karlson to the Government Analyst in Hobart for assay, the "rock" was reported to be of no commercial value.

"Quite a rush for sections in the vicinity of the Blow commenced in the spring of 1886, and parts of interests in the Blow sections secured over the protection area, three of which were reward claims of 15 acres each, changed hands at high figures. A company, called the Mount Lyell Gold Mining Company, was eventually formed to acquire the property, which consisted of 75 acres. Prospecting was carried on by tunnels and drives, and 1,874 tons of the gossan were crushed, which yielded 1,670 ozs. gold and 852 ozs. silver. But the work did not prosper, for the ironstone was difficult to treat with the primitive methods adopted, as the barytes in the hematite prevented ready amalgamation, while the gold in the supposed alluvial deposits was too sparse to pay. Small slugs of native copper were occasionally met with by the prospectors, but it was never suspected that the pyrites contained copper.

"In 1885, W. H. Glover, Commissioner of Mines, reported on the workings on the field.* He stated:—'There is also underfoot on the ground' (*i.e.*, below the Blow) . . . . 'a large mass, apparently a continuous lode, of pyrites, and persons assuming to be conversant with the subject are of opinion that this will prove to be the identical lode from which the gold has been shed. It is, however, to be regretted that the proprietors have never yet sent any portion of this pyrites for analysis.'

"Glover was in error in stating that no pyrites had been sent away for assay, it already having been mentioned that Karlson had sent samples to the Government Analyst."

* His report is republished by Macnamara Russell in his work "Mount Lyell Mines Tasmania," 1896, pp. 9–11.

The alluvial workings on the field were in a deposit 50 feet in thickness; it was worked below the Iron Blow by the M'Donough Brothers and the Linda Sluicing Company. Further up the creek was a lease held by J. S. Karlson, while a miner named Delaney began work lower down the creek, near what is now the Linda township. This auriferous deposit was presumed to be ordinary alluvial material, but most of it was in all probability part of a moraine, formed by the action of a glacier, which at no very distant period filled the whole of the eastern part of the Linda Valley.

Thureau, the Government Geologist of Tasmania, reported on the mining field in 1886, and was impressed with the unusual character of its ores; he stated that "the deposit was not similar to any lodes, reefs, or even dyke formations that he knew." The mining results were still disappointing, but, with the magnificent perseverance of the Australian miner, the men would not abandon the field, and they gradually learnt the great extent of its mineral resources.

In 1890, Montgomery, who had succeeded to the post of Government Geologist of Tasmania, again called attention to the field in his "Report on the State of the Mining Industry of the West Coast." In August, 1891, Mr. Bowes Kelly, attracted by the fame of the great Mount Lyell ore mass, visited the locality. The vigorous development of the field mainly resulted from that visit. Mr. Bowes Kelly fully inspected the Iron Blow, and some of the ore was sent to the Broken Hill Proprietary Smelting Works; there it was examined by Mr. H. H. Schlapp, who subsequently himself visited Mount Lyell. Mr. Bowes Kelly and his advisers concluded that the ore would not pay to work as a gold mine, but that, if attacked on a sufficiently large scale, the pyrites could be worked for copper, and the gold and silver gained as bye products. A syndicate, of which Mr. Bowes Kelly was the most active member, further prospected the field. This led to the formation, by Mr. Kelly and his party, of a company named the Mount Lyell Mining Company, No Liability, which was superseded subsequently by the Mount Lyell Mining and Railway Company Limited, incorporated in 1893. In that year Dr. E. D.

Peters, jun., the well-known authority on the metallurgy of copper, visited the district. Peters' report, accompanied by those of Mr. T. A. Allan, formerly manager of the Mount Tharsis Mines in Spain, and of Mr. Montgomery, demonstrated the practicability of the successful working of the mine; and, largely thanks to Peters' report and the discovery of a rich bonanza of silver-copper ore in the mine, adequate capital was subscribed, and the development of the property seriously begun.

On the recommendation of Mr. Schlapp the company secured the services of Mr. R. C. Sticht, to whose administrative capacity and expert metallurgical skill the subsequent success of the company has been so largely owing. Mr. Sticht, in a report on 8th April, 1895, proposed that the ore should be treated by pyritic smelting, the sulphur and iron in the ore being used as the fuel for its own smelting, instead of by the ordinary process of reduction by roasting, which Peters had recommended. Mr. Sticht's recommendations were adopted; smelting furnaces were erected in the Queen Valley, at Penghana, a mile and a quarter from where is, now, the township of Queenstown. The extraction of the ore from the mine was undertaken on the open cut system, recommended by Peters, under the management first of Mr. Lindesay Clarke, and since 1901 of Mr. W. T. Batchelor.

Peters had recommended that a tunnel should be driven from the No. 4 level in the mine under the divide between the Linda and the Queen Rivers. But instead of this costly undertaking, the company erected an aerial rope tramway and a haulage by which the ore is carried across the ridge to the Queen Valley. The first smelter started work in 1896, since which time the furnaces have been steadily alight. They have smelted, on an average, about 1,000 tons of ore a day.

Queenstown was connected with its port, Strahan, on Macquarie Harbour, by a railway, which was built by the Mount Lyell Mining and Railway Company. No easy route for the railway could be found, but after the survey of three lines it was decided to carry the railway across the ridge between the Queen Valley and the King Valley by a steep ascent and descent, worked upon the Abt

system. The railway was begun in November, 1894, opened to the end of the navigable part of the King River at Teepookana (the native name of the Kingfisher) in July, 1896, and subsequently extended to Strahan in 1899.

The discovery of the great Mount Lyell mine led to the rest of the Mount Lyell field being taken up on lease by mining companies. Many of the leases taken up had, as their main recommendation, the fact of their immediate proximity to the Mount Lyell mine, and their position upon the supposed line of strike of its great lode.

Some of these companies found pockets of copper ores and bands of pyrites, but most of them failed to find any deposit that would pay to work independently. Most of them have collapsed or been absorbed by the Mount Lyell Company; it has taken up some of their leases for tip heaps, and others for the low grade siliceous materials, which it can use as flux in the smelting of its own pyritic ores.

A list of the chief companies who held leases on the Mount Lyell field in 1900 is as follows:—

LIST OF MOUNT LYELL MINING COMPANIES HOLDING LEASES, 5TH JUNE, 1900.

Name of Company.	Date of Lease.	Area of Lease.		
		a.	r.	p.
Mount Lyell Tasman Comstock Gold, Silver, Lead, and Copper Mining Company, No Liability ..	1893	39	0	0
Tasman Lyell Prospecting Association, No Liability	1891, '3, '7	293	0	0
Tasman and Crown Lyell Extended Mining Company, No Liability	1893	181	0	0
North Mount Lyell Copper Company Limited ..	1893	503	0	0
Mount Lyell Comstock Mining Association, No Liability	1896	20	0	0
Mount Lyell Mining and Railway Company Limited	1891, '2, '3, '6, '8, '9	2,384	0	0
Consolidated Mount Lyell Copper Mines Limited	—	78	0	0
Mount Lyell Peaks Mining Company, No Liability	1893	80	0	0

Name of Company.	Date of Lease.	Area of Lease. a.	r.	p.
Mount Lyell Blocks Copper Corporation, Limited	1892, '3, '6, 1900	314	0	0
Western Tharsis Mining Company, No Liability	1893	40	0	0
North Mount Lyell Consolidated Mining Company, No Liability	1891	70	0	0
Crown Lyell Mining Company, No Liability	1891	30	0	0
Lyell Blocks Consols Mining Company, No Liability	1893	89	0	0
Tharsis Consolidated Copper Mines, No Liability	1893	26	0	0
Lyell Tharsis Mining Company, No Liability..	1891, '3	26	0	0
Mount Lyell Consols Registered, No Liability ..	1889	20	0	0
*Mount Lyell Consols, No Liability	1892, '4	44	0	0
*Mount Lyell Extended Mining Association, No Liability	1889, '90, '94	28	0	0
Mount Lyell Consols Extended Mining Company, No Liability	—	3	1	36
Copper Mines of Mount Lyell West Limited ..	1893, '6	84	0	0
North Prince Lyell Mining Company, No Liability	1893	10	0	0
Prince Lyell Mining Company	1891, '3	25	0	0
West Lyell Extended Mining Company, No Liability	1891	20	0	0
Lyell Pioneer Consolidated Mining Company No Liability	1894, '5	56	0	0
British Transvaal and General Finance Company Limited	1891	40	0	0
*South Mount Lyell Mining Company Limited	1892, '3, '5	94	0	0
Mount Lyell Copper Estates Limited ..	1891, '3, '6	157	0	0
Duke Lyell Gold, Silver, and Copper Mining Company, No Liability	1893	80	0	0
Great Mount Lyell Copper Company Limited ..	1893	640	0	0
King River Prospecting and Gold Mining Association Registered, No Liability	1897	30	0	0

* "The South Mount Lyell Mining Company, the Mount Lyell Extended Company, and Mount Lyell Consols have mines on Mount Darwin, about 13 miles south of the Mount Lyell mines."—Twelvetrees, W. H., "Report on Mounts Huxley, Jukes, and Darwin," Mines Department, Hobart, 1900, pp. 17–20.

The following list of the companies now in existence I owe to the courtesy of Messrs. Greene and Brush, of 53 Queen-street, Melbourne :—

LIST OF COMPANIES ON MOUNT LYELL FIELD, 28TH MARCH, 1904.

CROWN LYELL COPPER COMPANY NO LIABILITY. 30 acres, at Mount Lyell. Capital, £250,000, in 200,000 shares of 25s. each, paid up to 20s. 11d. per share; 40,000 shares held in reserve. Manager: N. Madden, 60 Queen-street, Melbourne. 1d. calls are being made quarterly. Present market quotations :—Buyer, 3d.; seller, 3½d.

COPPER MINES OF MOUNT LYELL WEST LIMITED. About 80 acres, at Mount Lyell. Capital authorized, £400,000; capital issued, £230,000, in shares of £1 each, all fully paid. Registered in England in October, 1897. Secretary: H. A. H. Russell, 16 St. Helen's-place, London, E.C. Tasmanian Agent: J. B. Hickson, Hobart. No market value.

LYELL PIONEER CONSOLIDATED MINING COMPANY NO LIABILITY. 60 acres, at Mount Lyell. Capital, £72,000, in 72,000 shares of £1 each. 60,000 shares paid up to 11s. 4d.; 12,000 shares paid up to 20s. 1d. calls are being made quarterly. Manager: C. E. Packer, 31 Queen-street, Melbourne. No market value.

LYELL THARSIS MINING COMPANY NO LIABILITY. 21 acres, at Mount Lyell. Capital authorized, £150,000, in 150,000 shares of £1 each; capital issued, £123,000, in 123,000 shares of £1 each. Dividends amounting to 5s. per share have been paid—last, December, 1901, 6d. per share. Manager: John Potts, 31 Queen-street, Melbourne. London Secretary: Edwin Habben, Finsbury House, London, E.C. Present market value :—Buyer, 1d.; seller, 4d.

MOUNT LYELL MINING AND RAILWAY COMPANY LIMITED. 917 acres, at Mount Lyell. Capital, £1,300,000, in 1,300,000 shares of £1 each, 100,000 of which are unissued. £1,087,000 paid in dividends to 31st December, 1903. Last dividend paid 21st September, 1903,* 4s. per share (dividend and bonus). Secretary: Alfred Mellor, 39 Queen-street, Melbourne. Present quotations :—Buyer, 16s.; seller, 16s. 6d.; sales, 16s. 6d.

MOUNT LYELL ANACONDA MINING COMPANY NO LIABILITY. 38 acres, at Mount Lyell. Capital, £50,000, in 100,000 shares of 10s. each, all of which are fully paid. Manager: N. Madden, 60 Queen-street, Melbourne. Not working at present. No market value.

[* Another Dividend has since been paid.]

MOUNT LYELL CONSOLS NO LIABILITY. 130 acres, at Mount Lyell. Capital, £126,000, in 126,000 shares of £1 each. 66,788 shares paid to £1; 52,080 shares paid to 11s. 3d.; 7,132 shares held in reserve. Manager N. Madden, 60 Queen-street, Melbourne. Market quotations:—25th March, 1904:—Paid—buyer, 9d.; seller, 10d. Contributing—buyer, 4d.; seller, 9d.

MOUNT LYELL BLOCKS MINING COMPANY NO LIABILITY. 317 acres, at Mount Lyell. Capital, £300,000, in 300,000 shares of £1 each; paid to 18s. 9d. (including April call). Manager: Thomas Rollason, 47 Queen-street, Melbourne. London Secretary: C. S. Beale, 72 Bishopsgate-street Within, London. Present quotations: —Buyer, 2s. 5d.; seller, 2s. 6d.; sales, 2s. 6d.

MOUNT LYELL COMSTOCK COPPER COMPANY LIMITED. 93 acres, at Mount Lyell. Capital, £500,000, in 500,000 shares of £1 each; 50,000 shares held in reserve. Shares all fully paid. Manager: C. E. Packer, 31 Queen-street, Melbourne. No market value at present.

MOUNT LYELL TASMAN COMSTOCK GOLD, SILVER, LEAD, AND COPPER MINING COMPANY NO LIABILITY. 113 acres, at Mount Lyell. Capital, £60,000, in 120,000 shares of 10s. each. Manager: Bernard Bradley, 150 Queen-street, Melbourne. No market value at present.

MOUNT LYELL PEAKS MINING COMPANY NO LIABILITY. 80 acres, at Mount Lyell. Capital, £40,000, in 80,000 shares of 10s. each, 20,000 of which are paid up and remainder contributing. Manager: W. D. M'Whae, 90 Queen-street, Melbourne. No market value.

MOUNT LYELL EXTENDED COMPANY NO LIABILITY. 30 acres at Mount Lyell and 80 acres at Mount Darwin. Capital, £150,000, in 150,000 shares of £1 each; 90,000 shares paid to 15s. 5d.; 60,000 shares paid to £1; 24,760 shares held in reserve. Mine not working at present. No market value.

NORTH CROWN LYELL MINING COMPANY NO LIABILITY. 66 acres, at Mount Lyell. Capital, £125,000, in 125,000 shares of £1 each, 62,500 of which are fully paid. Manager: G. A. Lawson, 90 Queen-street, Melbourne. No market value.

NORTH MOUNT LYELL CONSOLIDATED MINING COMPANY NO LIABILITY. 70 acres, at Mount Lyell. Capital, £50,000, in 100,000 shares of 10s. each. Capital has all been called up and they have ceased work. Manager: N. Madden, 60 Queen-street, Melbourne. No market value.

PRINCE LYELL MINING COMPANY NO LIABILITY. 25 acres, at Mount Lyell. Capital, £100,000, in 100,000 shares of £1 each, 50,000 of which are fully paid. Manager: G. A. Lawson, 90 Queen-street, Melbourne. No market value.

QUEEN LYELL MINING COMPANY NO LIABILITY. Capital, £100,000, in 100,000 shares of £1 each, 50,000 of which are fully paid. Manager: G. A. Lawson, 90 Queen-street, Melbourne. No market value.

SOUTH MOUNT LYELL MINING COMPANY LIMITED. 96 acres at Mount Lyell and 80 acres at Mount Darwin. Capital, £600,000, in 300,000 shares of 40s. each; 51,925 shares held in reserve. Shares all fully paid. Secretary: N. Madden, 60 Queen-street, Melbourne. No market value.

TASMAN LYELL COPPER COMPANY LIMITED. 200 acres, at Mount Lyell. Capital, £300,000, in 300,000 shares of £1 each, all fully paid. Secretary: C. E. Packer, 31 Queen-street, Melbourne. No market value.

TASMAN AND CROWN LYELL EXTENDED MINING COMPANY NO LIABILITY. 181 acres, at Mount Lyell. Capital, £150,000, in £150,000 shares of £1 each; 75,000 shares paid to £1, and 75,000 paid to 2s. 10d. Manager: John Brandon, 47 Queen-street, Melbourne. Present quotations:—Paid—buyer, 7d.; seller, 9d.; sales, 9d. Contributing—buyer, 1d.; seller. 3d.

WEST LYELL EXTENDED MINING COMPANY NO LIABILITY. Capital, £15,000, in 60,000 shares of 5s. each, 20,000 of which are fully paid, and balance, 40,000, contributing. Manager: H. D. M'Kie, 92 Queen-street, Melbourne. No market value.

Of these companies only two have paid a dividend.

Outside the area of the Mount Lyell mine the other chief ore deposits are near the township of North Lyell, about a mile to the north of the parent mine. Here five mines have been worked with some measure of success.

The most important of these is the North Lyell mine, the richest part of which was discovered by accident during the cutting of a road. Its ores are the richest in the field. The mine was acquired by the North Lyell Mining Company, which had a nominal capital of £600,000, which it spent in the development of its property. It built a railway (begun in January, 1899) from its mine to Macquarie Harbour, and a steamer, the *North Lyell*, to run from Kelly basin to the chief port at Strahan and to Melbourne. The ore was carried by an aerial tramway from the mine to the railway terminus, a mile away, in the Linda township, and was thence taken to the smelting works at the township of Crotty, 10 miles distant. The North Lyell Company subsequently led to the working of

the South Lyell mine, by purchasing from it pyrites with which to treat its own acid ores. But owing to the expenses of its enterprise and the highly refractory nature of its rich, siliceous ores, the North Lyell Company was not financially successful. By 1903 it had spent over £1,250,000, it was burdened by debt, and being unable to pay its way independently, it agreed to amalgamation with the Mount Lyell Mining and Railway Company, the joint company retaining that name. This union was certainly the best step that could have been taken in the interests of the field as a whole; for the siliceous ores of the North Lyell mine serve as an economic flux in the treatment of the pyritic ores of the Mount Lyell mine, even the poorest of which can now be used as a fuel. The amalgamation has thus increased the life of both mines; but it has led to the abandonment of the town of Crotty and its smelters. The North Lyell railway has been practically stopped, as only one train a week is now run on it, to satisfy the requirements of its Act.

The Lyell Tharsis mine opened with prospects of success. It had a lease of 21 acres, on which was a band of mineralized schists 100 feet wide, though only 20 feet of it can be regarded as ore. The ore is a low grade siliceous bornite, occurring in veins 2 inches to 6 inches apart. It is so poor in iron that it forms an excellent flux for use with the Mount Lyell ores. The Lyell Tharsis Company wisely made no attempt to treat the ore itself, but sold it to the Mount Lyell Mining and Railway Company for use as a fluxing ore. An unfortunate accident delayed further attempts to develop the property, and it has made no important addition to the copper output of the field.

The South Tharsis and Royal Tharsis mines were both founded by independent companies, and were subsequently acquired by the Mount Lyell Mining and Railway Company. The South Tharsis held a lease of 20 acres on the western slope of the ridge between the Queen River and the Linda Creek, about one mile north of the Mount Lyell mine. It began to work its ore by an open cut, started in June, 1899, and by two tunnels. Its ore was pyritiferous schist; the specific gravity of the vein stuff or gangue

was 2·4, while that of its copper-bearing pyrites was 4·8. Hence the company proposed to separate its ores as concentrates, and erected a concentrating plant on a branch of Glover's Creek. The ore treatment was at first claimed as successful, but it failed ultimately; and the mine was acquired by the Mount Lyell Mining and Railway Company, which could successfully use its ores as a flux. The Royal Tharsis mine, with a lease of 40 acres, has a similar ore to that of the adjacent lease of the Southern Tharsis. It also has been acquired by the Mount Lyell Mining and Railway Company; but, as most of the ore has to be obtained by underground mining, it has only been worked on a limited scale.

The Mount Lyell Blocks is of interest, as the mine is very different from any other on the field. It was founded under the name of the Stanley Copper Mine by a syndicate from Sydney. The property is traversed by a band of copper-bearing clay, from which the copper was separated by washing. The concentrated copper was sent to Sydney. The company spent £3,000 on the property, but failed to make the mine pay. From June, 1898, to June, 1899, it was held by a Melbourne company, who gave it its present name, from the fact that its lease consists of seven ten-acre blocks. The manager, Mr. R. Schloesser, found upon the lease a large body of siliceous bornite and copper pyrites, by means of a tunnel 1,170 feet long. The ore body is said to be 40 feet broad and 60 feet high. But again the efforts were unsuccessful. In 1903 the company was re-organized, and active prospecting work is now proceeding.

PART II.

GEOLOGY OF THE FIELD AND ITS MINES.

CHAPTER V.—PREVIOUS LITERATURE.*

The first account of the geology of the Mount Lyell mining field was published in 1886 by G. Thureau,† then Government Geologist of Tasmania. He described the schists in which the main ore body occurs as volcanic muds, "simply thrown up by some kind of hydrothermal action at periods in the geological age which cannot at present be ascertained from the confined area I have been able to survey." Thureau suggested that the gold had been introduced either by a solution or as a vapour ascending from below.

In 1889, Thureau and R. M. Johnston both gave accounts of the Ironstone Blow in the Linda Valley, and in 1890, A. Montgomery published a further short report on the field; but it was not until the discovery of the great pyrites body beside the Iron Blow that prominent attention was directed to the mineral wealth of Mount Lyell. Then, in 1893, a series of important reports by Peters, Allan, and Montgomery first gave any general account of the structure of the field. Dr. E. D. Peters, jun., the well-known expert in the metallurgy of copper, visited the field on behalf of the Mount Lyell Mining and Railway Company, and in his report briefly described the geology of the pyrites body; he showed that it could be profitably worked, and prepared a scheme for its treatment. The most important part of his report dealt with the ore; but his metallurgical report was prefaced by a short account of its geological relations. He pointed out that the pyrites, with its admixture of copper, gold, and silver, is not only present in the great pyrites body, but occurs also in bands scattered through

* For references see Bibliography, Appendix III., pp. 164-168.

† Parl. Pap., Tasmania, 1886, Nos. 1, 46, 8 pp. and map.

the adjacent schist; and, according to his determinations, the precious metals occur in the pyrites in about the same proportions in the great ore bodies and in the thin pyritic bands. Peters described the main rock series, associated with the ores, as a band of hydro-mica schist, which stretches from Mount Owen for some 30 miles to the north-west. According to Peters, bands of conglomerate and quartzite, with numerous thin intercalated layers of pyrites, are interstratified in this hydro-mica schist; and he included practically all the rocks of the area as Silurian. The evidence available at the time led Peters to accept the view that the ore deposit was formed in a swamp, into which flowed water carrying in solution iron, copper, silver, and gold. The peaty, organic acids in the waters of the swamp precipitated the metals, which were then collected in a massive bed on the floor. The deposits were then covered with mud and gravel; subsequently the mud was altered into schists, and the pebbles cemented into the hard conglomerates; the whole series was then uplifted into its present inclined position. "Remembering, therefore," he said, "that its present so-called width or thickness was its former depth when in its original position, we may see what an enormous depth we may look for. For what we call depth now was, of course, originally its lateral or longitudinal extent. And we all know that the surface extent of an ordinary pool is many times, usually many scores of times, greater than its depth. As the present thickness (former depth) is over 300 feet, we may reasonably expect its extent into the earth (former surface) will be far deeper than we can follow it. And this agrees with practical experience; for out of the scores of deposits with which I am familiar, and some of which have been worked since the days of the Romans, I do not know of one that has failed in depth."

Peters' report to the Mount Lyell Mining and Railway Company was accompanied by one from T. Alexander Allan, who had formerly been general manager of the Tharsis mines in Spain. Allan's report was very suggestive. In reference to the Iron Blow he remarked that "this mineral, which is quite distinct from the gossan, is of unusual occurrence in this class of deposits," and

"though no doubt derived from the lode, the immediate connection is difficult to explain." He did not accept Peters' swamp deposit theory, but described the pyritic masses as a lode; thus he speaks of "the outcrop of the lode, which is about 280 feet in width at the centre" (p. 25). He described the hanging wall as of a "hard grey metamorphosed schist, almost porphyritic in appearance"; and remarked that "the Spanish deposits occur either at or near the contact with porphyries of silurian schist." He further noticed that the ore body is nearly all pure pyrites, and is almost free from barren material. He contrasted the Mount Lyell with the similar ores of southern Spain, which occur in larger masses, but contain less precious metal, and are poorer in copper.

A third report issued at the same time as those of Peters and Allan was by A. Montgomery, then Government Geological Surveyor of Tasmania. He also regarded the deposit as similar to the well-known pyritic masses of Europe, and especially mentions those at Rammelsberg, in the Harz, and at Rio Tinto. He lays stress on the fact that, both at Rammelsberg and Mount Reid, a Tasmanian locality to the north of Mount Lyell, the pyritic deposits are interstratified conformably with the slates or other country rock. Hence he adopted the sedimentary origin of the deposits and their probable development in a series of lenticular masses. This view led him to anticipate that the ore would be unusually uniform in quality, and that it would extend to great depths. From the sedimentary origin of the deposit he anticipated that the ore would be best in the middle, and that it would be more and more mixed with bands of country rock toward the edges of the lenses. He considered the possibility of the pyrites body thinning out below, but remarks that "it is just as likely that the present surface of the ground may be far above the centre of the lenses, and that they will increase in size going down." He inferred that the ore masses must be very great, "the purity of the ore being to a great extent a guarantee that it was deposited far from the shores of the original basin." Another important deduction that followed from the swamp deposit theory is "that the value of the ore, in metals, is likely to be very uniform throughout each layer, the mineral having

been precipitated from uniform solutions." He anticipated some local enrichments due to secondary action. He attributed the iron of the Iron Blow to material removed from the pyrites body by solution, and precipitated at the contact of the pyrites and the country rock. He admitted, however, that the occurrence of this ore as hematite was puzzling, because the decomposition of pyrites forms limonite and not hematite.

Montgomery, in a paper published the next year, gave further information on the Mount Lyell field in an account of glacial action in Tasmania; he there* classified the conglomerates of western Tasmania into three distinct series:—

1. A conglomerate of pebbles of micaceous schists and quartzites, which still retains its original horizontal bedding, and is unconformable on the underlying schists and quartzites; it is of Permo-carboniferous age.

2. A similar series of conglomerates near the southern end of Mount Murchison, which are perhaps the Devonian conglomerates of Moore.

3. "A somewhat similar conglomerate, conformably bedded with the quartzites and schists and intercalated in layers in them." This division includes the conglomerates of Mount Owen, Mount Zeehan, and part of Mount Reid.

In a second report by Montgomery, published in 1894, he raises the question, as to whether the conglomerates associated with the Mount Lyell schists are of the same age as those which form the summits of Mounts Lyell and Owen. He states that the latter conglomerates "are conformably bedded with sandstones and schists," in which case they must be of the same age. But he concludes the same passage with the statement that "it is not certain that the schists containing the Mount Lyell pyrites deposits are of the same age as the conglomerates of Mount Owen, but the presumption appears to be that they are so, there being as yet no evidence, so far as I know, of their being of more ancient formation."†

* Montgomery, A., "Glacial Action in Tasmania," Proc. Roy. Soc., Tasmania, 1893 (1894), p. 160.

† Montgomery, A., "Notes on the Queen River and Mount Lyell Mining Districts," Geol. Surv. Office, Tasmania, 9th July, 1894.

The first advance beyond the conclusions of Peters and Montgomery is in a paper by Messrs. Graham Officer, L. Balfour, and E. G. Hogg, in 1895. They gave a short account of the geology of the district around Mount Lyell, and referred to the complexity of its geological problems. They stated that the lowest rocks of the series are "schists (generally hydro-mica), sandstones, quartzites, and conglomerates; these are all inclined at high angles, and have been assigned to Lower Silurian age." They, therefore, suggest that the schists are Cambrian, or even Archean, though they note that certain Lower Silurian fossils have been found in their vicinity. They accepted two distinct conglomerates—an older series interstratified with the schists, and an upper series, which forms most of Mounts Owen and Lyell, and is of much later age than the conglomerates associated with the ore bodies. They remarked, for example, that the massive conglomerates of Mounts Owen and Lyell are "resting unconformably on the oldest schistose rocks, with their accompanying sandstones and conglomerates." In regard to the ore deposits, they accepted the theory of Peters and Montgomery as the most satisfactory.

In 1898, Messrs. W. H. Twelvetrees and W. F. Petterd described the plutonic rock at Lynchford as an altered and mechanically deformed rock, composed of orthoclase, plagioclase, augite, and quartz, and they referred to the pyritic bands traversing the schists, as possibly of sedimentary origin.

By the year 1900 mining work had exposed better sections of the rocks, and so cleared the formerly impenetrable scrub that detailed evidence as to the relation of the Mount Lyell ore bodies was available. In that year E. Haber, who had visited Tasmania on behalf of a German syndicate, published an interesting paper on the sulphide ores of western Tasmania. He described the schists of the Mount Lyell field as "a kind of greenstone, of a dark to light green colour, and granular to foliated in structure." He suggests that this rock was submarine diabase, and calls it "schalstein"—a term used in Germany particularly for diabase tuffs, and sometimes applied to any crushed and altered basic igneous rock of great geological age. The Lyell schist, however,

is acid. The following extracts from Haber's report explain his theories regarding the field.

Haber states that "the schalstein borders on a system of beds of sandstone and quartz-conglomerate, which in general seem to underlie it and form its base. The contact, nevertheless, is not sharp." "The strike of the schalstein is generally 112° 30′ with a steep dip of 75° to the south-west." As a rule ores are seen in the schalstein only when the rock is strongly magnified, but "there occur, manifestly following the lines of cleavage in the rocks, bands and zones with higher contents of ore, which for the sake of brevity in the following report may be called fahlbands." The width of the fahlbands varies from but a little, to over 100 metres. The ore bodies he describes as "of a lens-shaped form, sharply bounded, and passing obliquely across the strike of the schists in a north-westerly direction, whereby they also seem to be less horizontal than the cleavage. He describes the ore bodies as "manifestly fillings of rents and cavities, which seem to have taken their entrance and exit points in the beds of hard sandstone and conglomerate."

In regard to the origin of the ores, he states that the crystalline form of the pyrites in the schalstein shows that the minerals were not mechanically deposited there; and he leaves it an open question whether the ore stuff was contained in the conglomerate which bounds the schalstein, or whether it came up in solution from the "all-underlying plutonic rock masses." "The fahlbands are in any case to be regarded as ordinary ore formations; on the other hand, the nature of the siliceous ore bodies indicates for them a secondary origin." He holds that the mountain-foldings produced cracks and spaces; these were connected to the fahlbands, and the spaces were thus readily filled with sulphide ores by lateral secretion A definite connection between the fahlbands and ore bodies is shown, as barite occurs in both of them. He concludes that —"If this theory be accepted, then the siliceous ore bodies should represent comparatively superficial formations in contract to the fahlbands." The barytic hematite bodies he describes as contact formations, whether the material came from the schalstein or from

the underlying plutonics; but these ironstones, according to Haber, had nothing to do with the ore bodies.

The evidence obtained by further mining work did not confirm Peters' theory, to which the officers of the Mount Lyell Company were never to any extent adherents. They remarked the patent fact that the pyrites bodies occurred near the contact of the conglomerates and schists. The ore bodies were accordingly described as contact formations; but it was fully recognized that the ore deposits were not contact formations in the ordinary sense, as they were generally wholly enclosed in the schists.

At the end of 1900 a general account of the geology and history of the field was published by H. J. Daly, from information which, I understand, was mainly collected and supplied to him by the company's officers. Daly accepted the view that "the whole region belongs to the Silurian period." In reference to the conglomerates, he says that "it is easy to observe two distinct geological ages. The coarse, fragmental conglomerate is of a more recent age than that of the close-grained, hard, red sandstone and quartzite, which occur in well-defined beds." He accepted the view which he first expressed in print, that the ore bodies are a contact formation at the junction of the conglomerates and schists. He therefore advocated further prospecting along the line of contact, although many parts of it had been proved to be non-productive.

Sydney Fawns, in 1901, published two analyses made by C. Rae, of the schists from the northern part of the Mount Lyell field, from the leases of the Tasman and Crown Lyell Extended Company. He identified the country rocks of the ore deposits as felsites and grey schists, and as underlying the conglomerates and quartzites. A further series of analyses of the Mount Lyell ores, rocks and metallurgical products was published by H. Stewart in 1902.

Twelvetrees, in his recent paper, "The Outlines of the Geology of Tasmania," has several references to the geology of this field. He correctly described some of the schists as schistose porphyries and felsites, with which he considered the green augite syenite

of Lynchford was probably connected. The Mount Lyell schists he referred to the upper or middle Silurian, on account of the fossil brachiopods found at Gormanston; he suggested that the schists "belong to the Queen River series, greatly metamorphosed."

The contact theory of the deposits, first published by Daly, has also been adopted in a map and a report prepared for the Mount Lyell Mining and Railway Company by Mr. W. H. Cundy, of Bendigo. The conglomerates capping Mounts Owen and Lyell were represented on his sketch map as lying unconformably upon the conglomerates associated with the schists.

Chapter VI.—The Mount Lyell Schists.

(A.)—Summary of previous opinion.

The schists of Mount Lyell form the basal member of the rock series in this part of Tasmania. Five distinct views have been expressed in regard to their origin and relations. In the first place they were described by Thureau as volcanic muds, a view somewhat similar to that of Haber, who regarded them as eruptive submarine diabases or schalsteins. Secondly, Peters and Montgomery represented them as a series of sediments interstratified with the conglomerates and ores, which latter were formed as deposits in a swamp; they regarded the whole rock series as of Silurian age, a view re-stated by Daly in 1901. Thirdly, Officer, Balfour, and Hogg suggest that the schists are "Cambrian, or even Archean," and that they are associated with some accompanying sandstones and conglomerates of the same age, but are covered unconformably by the massive conglomerates of Mounts Owen and Lyell. Fourthly, Mr. Twelvetrees regards the schists as Silurian, belonging to the lowest of the four subdivisions of the middle and upper Silurian of Western Tasmania. He states (p. 4) that the Lyell schists "cannot be placed definitely, but, from fossil brachiopods found at Gormanston, it seems possible that they belong to the Queen River series, greatly metamorphosed." Mr. Twelvetrees also considers that the felsites are connected with the "augite syenite" of Lynchford; and the upper conglomerates of the West Coast Range, which form the heavy caps of Mounts Lyell, Owen, &c., he puts as the uppermost division of the three divisions of the Devonian.

The fifth view that has been expressed is that, instead of the schists being older than the conglomerates, they are a younger series of deposits; this view is based on the fact that the footwall of the ore body is conglomerate, while the overlying hanging wall is schist.

(B.)—DISTRIBUTION OF THE MOUNT LYELL SCHISTS.

The schists are best exposed on the western slope of the ridge which forms the divide between the Queen and the upper part of the King Rivers. In the southern part of the field the outcrop of the schists is about two miles wide, and still further south they must be wider, as they cross the divide south of the summit of Mount Owen, and there appear to extend eastward to the King River. At the haulage they are more narrow, being reduced to one and a half miles in width; and beyond that point they are interrupted by the igneous rocks, which occupy most of the northern half of the area known as the Reserve Leases of Mount Lyell. The schists here are reduced to a narrow band between the left bank of the East Queen River and the western spur of Mount Lyell; for the area between the East Queen River and the Silurian beds to the west is occupied by igneous rocks. Further north the series extends to the east along the Sedgwick valley and round the northern foot of Mount Lyell, until the outcrop is covered by the glacial deposits of the King glacier.

Speaking generally, the strike of the schists is from north 50° to 60° west, to south 50° to 60° east, with a dip south-westward of from 60° to 80°. At the northern end the schists are bent till the strike is north 70° east, and there is a north-westerly dip of about 60°. These figures can only be accepted very generally, the rocks having suffered many faults and dislocations, and the strikes, in places, being very confused. The schists along the eastern border often dip 70° towards the west. Following the beds southward from opposite the western buttress of Mount Lyell the average strike is as follows:—

The North Crown Lyell Company's lease, 120°.

In the Western and Royal Tharsis, from 130° to 135°.

In the north-western leases held by the North Mount Lyell Company, 136°.

At the foot of the South Tharsis concentrating mill, 160°.

By the engine-house on the top of the haulage, 120°.

Along the crest of the ridge to the south of the haulage, from 110° to 120°.

In the bed of the Conglomerate Creek, at the tunnel worked by the Reserve Company, and in many exposures on the Lynchford track on the western foot of Mount Owen, usually about 120°; but where the schists are crushed against the conglomerates, at the western foot of Mount Owen, it is in places 105° and 87°.

On the road from Gormanston to Queenstown, 135°, dipping to the north-east.

Speaking generally, the average strikes of the district seem to be from 120° to 130°—that is to say, from north 50° to 60° west, to south 50° to 60° east; but in places the strike is altered by the intrusion of igneous rocks, and by the schists being crushed against the conglomerates. As a rule the strike is fairly regular, though in some bands along lines of faulting it is extremely confused, as, *e.g.*, west of the Glen Lyell lease, and one-third of the way down the Lyell Tharsis aerial tramway.

(C.)—PETROGRAPHY OF THE SCHISTS.

The schists in which the ore masses of Mount Lyell occur were described by Dr. Peters as hydro-mica schists. Hydro-mica means, in general, that variety of muscovite known as damourite—a mineral which is certainly present in many of the coarse-grained rocks of the schist series. But the name hydro-mica was also used for various species of chlorites, chloritoids, and talc. It is not clear in what sense it was first applied to the Mount Lyell schists.

These schists consist, in the main, of a material which, when examined by the naked eye in hand specimens, seems talcose and chloritic. It has a greasy, pearly lustre, and scaly texture. Under the microscope the rock is seen to contain some aggregates and seams of quartz, chlorite, and white mica; but the bulk consists of an ill-defined base, of which the identification is not easy. Under a low power of the microscope it may appear structureless or granular; but it polarizes brightly, though in no perceptible colours. Under a high power of the microscope, the base may

remain cryptocrystalline or granular, or it may be resolved into a mass of small scales of a white mineral, which has a well developed basal cleavage, and between which are scattered crystalline granules. Without the aid of chemical analysis, the microscope would be able to carry the interpretation but little further. If this material had been small in amount, it would have been sufficent simply to call it pinite, and trouble no more as to its precise character. But this material forms so large a proportion of the Mount Lyell schists that this easy treatment is not justifiable.

The term pinite is used for a great number of secondary products formed by the alteration of various minerals. The pinites agree in having approximately the chemical composition of muscovite, and they are generally regarded as a massive, compact form of that mineral. They contain typically 8 to 10 per cent. of potash and about 4 per cent. of water. A series of analyses of these schists are available; and the highest percentage of alkali present in any of the schists is (analysis table, p. 159, No. 3) only 3·16 per cent. of potash, in a rock which contained 17·6 per cent, of alumina. An analysis (Appendix I., p. 159, No. 2) of a typical rock of this series, from the North Lyell tramway, gave—

Alumina	14·0 per cent.
Potash	1·5 per cent.
Soda	1·8 per cent.
Total loss of ignition	2·3 per cent.

One of the most conspicuous features of the material in question is its greenish colour, which is sometimes chloritic and at other times saussuritic. This greenish material sometimes occurs in nodules of remarkable purity; and one of them, analyzed by Mr. A. S. Wesley, showed that the mineral was composed entirely of silica, alumina, and water. The absence of magnesia and scarcity or absence of alkalies shows that it cannot be regarded as a true pinite. Mr. Beardsley suggested that it was a variety of pyrophyllite. Stewart has also identified one of the schists of the Lyell Tharsis mine as containing pyrophyllite veins; but the mineral in question is not a bisilicate, and therefore cannot be pyrophyllite (*cf.* note on p. 163). The composition stated in

analysis No. 7 (p. 159), the comparative infusibility of the material, and its very low water contents are points in which it differs from a typical pinite. The rocks of the Mount Lyell schists are, moreover, very poor in lime; accordingly they cannot include any considerable amount of the lime-mica, margarite.

Studies of a series of microscopic slides of these schists show that they have originated by the decomposition of felspars and felspathic material; some of the quartz has been set free, as a secondary quartz mosaic. The rest of the silica and the alumina has been left as a decomposition product, which is probably most nearly allied by chemical characters to margarodite. It is, perhaps, unwise to adopt that term for this material, but it saves the introduction of another, and it seems to me a fair extension of its use. The name margarodite was invented by Schafhautl for the soft talcose-like mica of Mount Greiner, south-east of Innsbruck, in the Tyrol. The analysis of this material is as follows:—

Silica	47·05
Alumina	34·9
Ferric oxide	1·5
Magnesia	1·95
Potash	7·96
Soda	4·07
Water	1·45
	98·88

Schafthautl regarded his margarodite as a distinct mineral. According to Tschermak* what is called margarodite is optically very similar to muscovite, but shows, on the other hand, some resemblance in lustre and in its somewhat greater brittleness to paragonite and margarite. Dana† interprets Tschermak as representing it as a mixture of those micas with muscovite, which is the view herein adopted. And though the Mount Lyell material must be poor in margarite, an analysis (No. 3,

* Tschermak, G., "Die Glimmergruppe I.," Zeit. Kryst., vol. ii. (1878), p. 46 also in "Sitzber. K. Akad., Wiss. Wien.," vol. lxxvi., pt. 1, 1877 (1878), p. 139.

† Dana, J. D., "System of Mineralogy," 6th edit. (1892), p. 616.

App. I., p. 159) shows that there is an appreciable quantity of lime present in some of the material, and it is probably present as margarite. The analysis in question shows 3·48 per cent. of lime, 1·8 per cent. of soda, and 3·16 per cent. of potash. It seems justifiable, as well as convenient, to extend the term margarodite to cover such compact and partly cryptocrystalline aggregates of white micas.

The margarodite base of the Lyell schists may be regarded as composed of a very fine grained intermixture of paragonite (white soda mica), and one of the varieties of damourite (white potash mica), with occasional inclusions of margarite. These minerals are not always present in a crystalline form, but the crystalline patches pass off imperceptibly into cryptocrystalline and granular material. The material has no doubt been formed from the decomposition of an alkali felspar, from which most, or all, of the alkalies have been leached away.

The rocks forming the Mount Lyell schists may be grouped into three main divisions:—

1. Schists which are completely altered and show no trace of their original constituents. The rocks of this group are sometimes nodular, and at other times are regular, well-bedded schists.

2. Schists which show traces of their original structure.

3. Schists associated with the igneous rocks of the Queen River, which can be definitely recognized as of igneous origin, and formed by the alteration of quartz-porphyrites and probably also of acid volcanic tuffs.

I.—*The Completely Altered Schists.*—The group of schists in which there is no trace of any of the original constituents contains greenish nodular schists, with crushed nodules surrounded by scaly, pearly layers.

The typical nodular schists from the North Lyell tramway (such as No. 29,* Pl. I., fig. 1), just to the north of the cutting

* These numbers refer to the specimens in the author's collection from Mount Lyell in the Geological Museum of the Melbourne University.

through the spur north of the Razorback, are massive, schistose, and nodular. They are dark green in colour, with spots and streaks which, examined in hand specimens, appear almost black. The rest of the rock is light green, with a saussuritic colour. Examined microscopically it is seen to contain occasional quartz grains, with some seams of secondary quartz. Chlorite is present in bands and in squarish angular patches; but the amounts, both of chlorite and quartz, are comparatively small. The chlorite is pleochroic, from a bright green to yellow; it is developed in radial groups, and has the deep prussian blue polarization colours typical of pennine. The main bulk of the rock consists of an indefinite massive granular material, which under a low power merely polarizes brightly, but gives no polarization colours and no definite character for identification. But when examined under a high power the structureless material passes into patches of sericitic mica, so that, but for the chemical composition, it might be called pinite.

An analysis of this rock, which has kindly been prepared at the Mount Lyell Laboratory for me by Mr. A. S. Wesley, is as follows:—

Silica	76·0 per cent.
Alumina	14·0 per cent.
Iron	3·6 per cent.
Lime	0·4 per cent.
Potash	1·5 per cent.
Soda	1·8 per cent.
Loss on ignition	2·3 per cent.
	99·6 per cent.

The 3·3 per cent. of alkalies no doubt occurs in the scattered scales of white mica, which, from its chemical character, may be regarded as a mixture of the damourite and paragonite; the rest of the base is a cryptocrystalline, hydrous silicate of alumina, which is a decomposition product from felspar and felspathic material, and may be conveniently called margarodite (*cf.* pp. 38, 39).

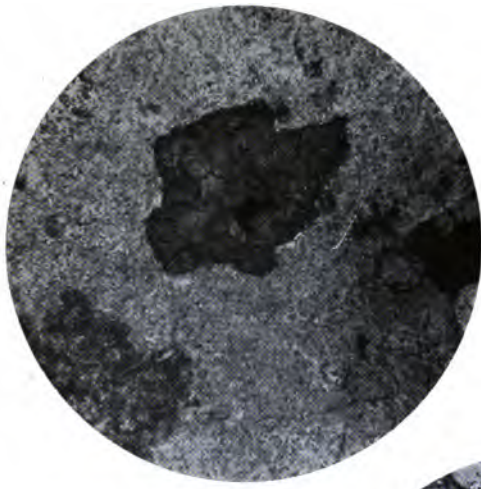


FIG. 1.—TYPICAL NODULAR SCHIST.—From the North Lyell Tramway, containing a large dark group of chlorite in a fine granular base.

Ord. light. × 30 dia. [No. 29].

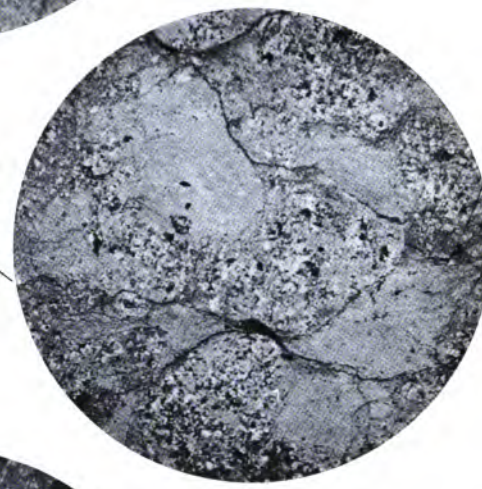


FIG. 2.—MARGARODITE SCHIST.—With thin chloritic bands and quarries of quartz mosaic, enclosing lenticles of margarodite. North Lyell Tramway.

+ Nicols. × 11 [No. 30].

FIG. 3.—NODULAR SCHIST.—With radial groups and, in places, a felt of large flakes of white mica. The opaque, thick crystals are pyrites. Beside the Great Lyell Fault, North Lyell Mine.

Ord. light. × 55 dia. [No. 44].

PHOTO—H. J. GRAYSON.

MOUNT LYELL SCHISTS.

Rock No. 30 was collected in immediate contact with the former specimen, and just to the north of it. Microscopically it appears (Pl. I., fig. 2) to be a nodular schist of a grey colour, with a faint tint of yellow; some patches of chlorite can be seen in it. The lustre is pearly, and the structure roughly schistose, the bulk of the rock consisting of greyish-white eyes, separated by the chloritic bands. The rock is soft, the hardness being about 3; it is very talcose in aspect and to the touch. Examined microscopically the bulk of the rock appears to be of the granular variety of margarodite. It polarizes brightly, but remains almost colourless. Quartz occurs in bands of a fine-grained mosaic, or is scattered irregularly throughout the base, as if set free by the decomposition of the original mineral. Titanite occurs very abundantly in aggregates of opaque, yellowish-white rods and rough aggregates. The base under a high power is resolved to a scaly mass in which some of the constituents are often radially arranged. These polarize in bright colours, ranging from blue to white. The foliation lines are very imperfect, and they pass, somewhat like a flow structure, around the lenticles of the margarodite.

Some typical nodular schist occurs beside the contact at the North Lyell mine. Most of the rock (Pl. I., fig. 3, No. 44) is of a light greenish-grey tint; in places, especially in bands around the nodules, it is of a bright green colour. The green material is similar in its nature to some specimens, of which Mr. Beardsley had analyses prepared. The central nodules in this rock are composed of the ordinary margarodite, passing into coarse-grained, radial aggregates of white mica. These aggregates are large and indefinite in their boundaries, in places becoming a felt of mica flakes. Irregular granules and sharply-bounded crystals of pyrites are abundantly scattered through the rock. The scaly material which surrounds the green nodules is mainly of fine white mica. There is no chlorite in the slide examined.

No. 45 (Pl. II., fig. 4) was collected at a point adjacent to No. 44. The rock is exceptionally well foliated, and consists in the main of a mass of white mica, which polarizes brightly. Quartz grains occur along the foliation planes, and there are numerous crystals of magnetite and ferrite.

A coarse schist (No. 47, Pl. II., fig. 5) occurs among the massive schists of the Nos. 30–33 series, along the North Lyell tramway. The rock is dark green in colour; it has an ill-defined, irregular foliation, and apparently consisted of a base of the margarodite material with a few quartz phenocrysts. The extreme alteration of the rock has, however, converted the base into a fine-grained granular mosaic, which appears to consist mainly of quartz and white mica. This mica has been developed irregularly through the original paste. Chlorite occurs in aggregates and in sparsely disseminated grains where the mosaic has been developed.

The history of this rock is interesting, as it has undergone a double metamorphism. The rock was first turned from a porphyrite or a porphyritic tuff into a margarodite schist; and this secondary margarodite material has then been altered in part into quartz and white mica. It is no wonder, therefore, that the original nature of some of the Lyell schists is quite unrecognizable.

A sample (No. 226) of schist from the Lyell mine (No. 6 bore at the No. 8 level, 10 feet from the contact with the conglomerates), is a dark bluish-grey schist, with bands and inclusions of a light reddish material. The hardness of the whole is about 6. It is well foliated and contains abundant crystals of pyrites developed in bands; and these pyrites are often associated with a porcelain-white and opaque mineral, the variety of titanite, described as leucoxene. There are some large quartz grains, and it is only on the margins of these grains that the quartz is in the form of mosaic. Bands of the damourite are here well developed, with bright polarization colours, and there is a little chlorite.

No. 203 is a sample of schist from the contact with the main ore mass on the hanging wall side at the main tunnel of the No. 5 level. It is a crushed, imperfectly foliated schist of a dark grey colour, with abundant pyrites scattered through it, and seamed by a network of grey-white veins.

Of the finely laminated schists, perhaps the most typical specimen is No. 216, from the Mount Lyell mine, from the No. 8 level at the commencement of the No. 1 crosscut, off the northern contact, and 150 feet from the shaft. It was collected for me by Mr.

FIG 4.—THINLY FOLIATED SCHIST.—From near the contact with the conglomerates, North Lyell Mine. The rock consists mainly of parallel bands of white mica; the black inclusions are magnetite.

+ Nicols. × 20 dia. [No. 45].

FIG. 5 — SCHIST WITH IRREGULAR FOLIATION. — Composed of bands of coarse and fine quartz-mica mosaic and some phenocrysts of quartz. North Lyell Tramway.

+ Nicols. × 20 dia. [No. 47].

FIG. 6.—FISSILE CHLORITE SCHIST.—With bands of white mica and pyrites. Beside the Great Lyell Fault, No. 8 Level, Mount Lyell Mine.

Ord. Light × 31 dia. [No. 216].

PHOTO—H. J. GRAYSON.

MOUNT LYELL SCHISTS

Batchelor. The rock is dark grey in colour, it is fissile, and is a well-cleaved chlorite schist, in places having a greenish tint. Examined microscopically the foliation laminæ appear very thin and regular, except where, as in the part figured (Pl. II., fig. 6), they are disturbed by thrust movements. The most easily determinable constituents are some thin layers of chlorite; some bands which give blue and yellow polarization colours; and some quartz mosaic, forming eye-shaped aggregates, and containing abundant very minute flakes of white mica. There are grains of rutile, and abundant sharply-defined crystals of pyrites, occurring both in cubes and octahedra. The bulk of the rock is composed of margarodite, which is here so crushed that it also shows well-defined foliation, and contains a large proportion of white mica scales An analysis of this rock, prepared by Mr. Bayly, of the Mines Department Laboratory, is given as No. 1 in Appendix No. I.

The bed of the stream, which rises near the ridge of Mount Owen, and, crossing lease No. 1,358/93M, joins Conglomerate Creek at the great bend south-west of the Gormanston Gap, is mostly of schist. A specimen (No. 60) collected near the eastern end of this tongue of schists, is a massive greyish-green rock, speckled with reddish-brown inclusions, having somewhat the aspect of iron-stained felspars. The rock was determined in the field as probably an altered felstone. The rock, examined under the microscope, is seen to be so decomposed that it is only determinable as a member of the schist series.

No. 221, from the Mount Lyell mine, is a dark slaty-grey schist with a regular foliation. It was collected for me by Mr. Batchelor from the end of the No. 1 cross-cut at the No. 6 level, and 89 feet from the junction of the north contact drive. It is composed mainly of the granular margarodite, with lines of quartz granules and abundant scattered crystals of pyrites. They are often developed in skeleton crystals, which have certainly been formed after the foliation of the rock, and are therefore proof of the metasomatic origin of these pyrites. Such skeleton crystals are shown in Pl. III., fig. 7. The pyrites is frequently associated with chlorite, and is sometimes built on and around the patches of leucoxene.

II.—*Schists which Retain Traces of the Original Structure.*—The next series of specimens of the schists is of interest, because the rocks show traces of at least part of the original constituents.

No. 189 was collected for me by Mr. Batchelor as a typical specimen of the Mount Lyell schists. It was obtained from the surface, apparently close to the mine. The colour of the fractured surface is a dull greenish-grey. The rock breaks into curved, wavy surfaces, along well-defined foliation planes. The aspect is scaly, but less talcose to the feel than in such specimens as No. 216. Under the microscope the foliation is seen to be very obscure, and hardly discernible. The most easily recognized constituent is quartz, which occurs in some large inclusions, which have been converted into a quartz mosaic, in which the granules, as usual, are of different optical orientation. There are some green aggregates of chlorite with pyrites in irregular patches. Some of the quartz grains have the form and concave margins often found in the grains of beds of volcanic ash. There are some grains, as in Pl. III., fig. 8, which still retain traces of the felspathic twinning. The rest of the rock is of granular margarodite, most of which contains no basally cleaved scales; but some patches (which can be picked out under a low power by their bright yellow and dark blue polarization colours), when highly magnified, are seen to be composed of minute flakes of white mica. This rock appears to be more regularly foliated than the specimens close to the contact with the conglomerates, and it retains sufficient traces of the original structure to suggest that it may have been formed from the foliation and alteration of a felspathic volcanic ash.

No. 192 is a schist collected from the surface in the immediate vicinity of the contact. It is of a pale slaty-grey colour, is greasy and soft to the touch, and easily rubs to powder between the fingers. It has a nodular cleavage, and the fractures leave irregular, humpy surfaces. Examined microscopically the bulk of the rock (Pl. III., fig. 9) is seen to be composed of the scaly variety of margarodite, with quartz grains disseminated through it. The rock is abundantly charged with pyrites, some of the

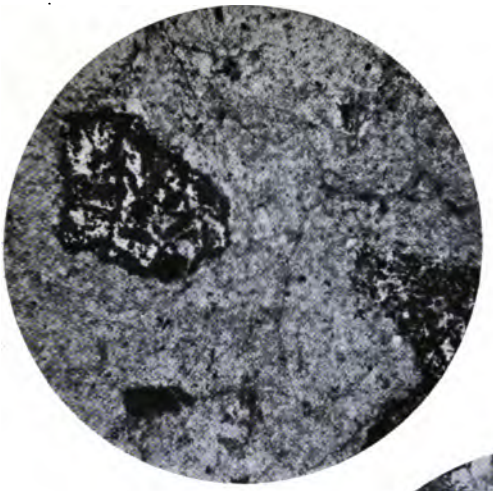


FIG. 7.—MARGARODITE SCHIST.—With skeleton crystals of pyrites. No. 6 level, Mount Lyell Mine.

Ord. Light. × 55 dia. [No. 221].

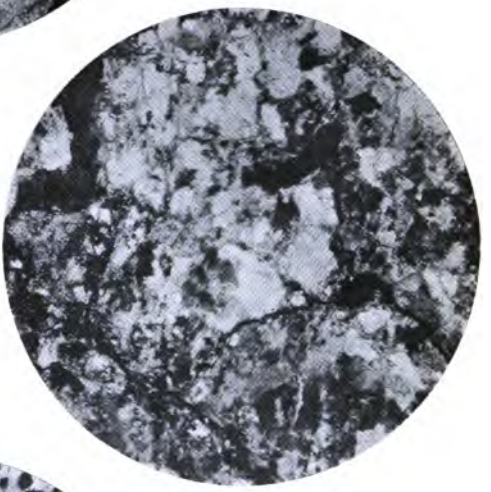


FIG. 8.—TYPICAL MOUNT LYELL SCHIST.—With obscure foliation, probably an altered volcanic ash. Surface, beside the Mount Lyell Mine.

+ Nicols. × 20 dia. [No. 189].

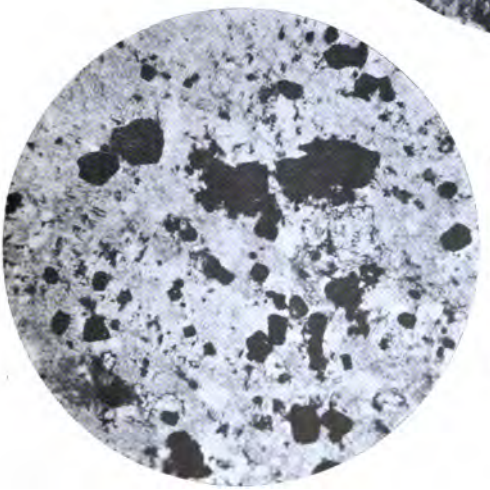


FIG. 9.—NODULAR CRUSHED MARGARODITE SCHIST.—With abundant pyrites, around which are radially arranged crystals of muscovite. Leucoxene occurs in some of the nests of pyrites.

Ord. Light. × 55 dia. [No. 192].

PHOTO—H. J. GRAYSON.

MOUNT LYELL SCHISTS.

aggregates of which are surrounded by white mica in short, squat crystals. The pyrites crystals occur both in cubes and octahedra; and they are often surrounded by or enclose flakes of leucoxene. There are one or two inclusions of margarodite material, which have a form suggesting derivation from felspars; but this rock is considerably more altered than the last, probably owing to its having been more severely crushed, in consequence of its proximity to the Great Mount Lyell Fault. The arrangement of the pyrites and leucoxene is interesting, as it suggests that the pyrites in this rock may have been derived by the pyritization of ilmenite.

No. 198, from the No. 5 level of the main tunnel, was collected for me by Mr. Batchelor in order to show the nature of the schists, where they have been preserved from any surface decomposition. The specimen was collected from north of the horse of schist from the main tunnel of the No. 5 level. It is a grey rock, with an earthy feel, and looks just like a decomposed schist. The base is scaly, but mostly consists of the cryptocrystalline variety of margarodite. It contains one large inclusion, which looks as if it had been a phenocryst of felspar in a fine base. The pressure structure is well marked by the arrangement of the constituents, and the whole rock is dusted with pyrites. There is no felspar, for the rock, having been in close contact to the Great Fault (p. 78), has been extremely altered.

No. 77 came from the sharp bend on the Gormanston road to the west of the Gormanston Gap, at a point close by a well-marked diabase dyke. The rock in the field appears as a typical talcose quartz schist. The general colour is a silky talc grey, with some patches of green, yellow, and pink. The foliation planes are irregular; some fine, dust-like grains of pyrites can be recognized by the naked eye. Examined microscopically (Pl. IV., fig. 10) it is seen to be composed, in the main, of a quartz mosaic, the grains being imbedded in a margarodite paste, which, under a high power, is resolved into the silky fibrous aggregates of sericite. There are some much larger quartz grains, some of which appear to have had fairly well preserved crystalline out-

lines, while others have been embayed by the ground mass; and these large quartz phenocrysts remain optically simple, except that some of them have passed into a mosaic on their borders. The aspect of this rock is that of a quartz felsite or quartz porphyrite, in which the whole of the original felsitic base has been crushed into margarodite and quartz mosaic.

The rock (No. 79) on the other side of the diabase dyke is a dark greenish-grey schist, with a very imperfect foliation and earthy texture. Its aspect is that of a crushed schalstein, as which these rocks were identified by Haber. Under the microscope (Pl. IV., fig. 11) the rock is seen to consist mainly of bands and a network of chlorite, surrounding transparent, colourless, but somewhat dusty grains. Under crossed nicols most of these grains are resolved into a mosaic of quartz. Here and there are patches which, when examined under a high power, are resolved into the silky fibrous texture of sericite. The chlorite, from the prussian blue interference colours, appears to be pennine. This rock may have been a quartz felsite, in which metamorphism has re-crystallized all the quartz as a mosaic, and the felspathic material has been turned into chlorite and sericite.

III.—*Schistose Quartz Porphyrites and Schistose Volcanic Tuffs.*—No. 157, Stubbs' Valley. This rock is a soft, green, scaly schist, which weathers readily to a soft grey clay. The foliation of the rock is ill defined. Examined microscopically it is seen to be a schistose porphyrite, of which the original constituents have been completely decomposed. The ground mass is granular, and has been re-crystallized, but patches of it still show schistosity. There are some large blotches of chlorite, which are sometimes roughly circular and at places lath-shaped. The latter are resolved, under crossed nicols, into aggregates of chlorite, epidote, and quartz, and were no doubt formed from felspar. There are some better-preserved remnants of the felspar, which show that it was once plagioclase. Some of the crystals of ilmenite have been broken across and the parts slightly displaced, while the mineral has been altered on the border to titanite. There can be no doubt that this rock was originally one of the Queen River porphyrites,

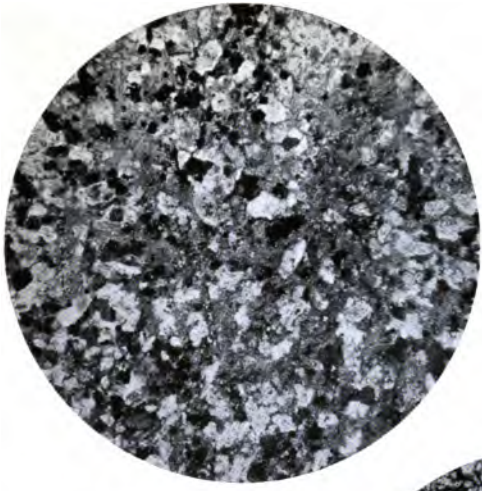


FIG. 10.—QUARTZ SCHIST.—Of a quartz mosaic, in a base of margarodite. Gormanston Road, west of the Gap.

+ Nicols. × 20 dia. [No. 77].

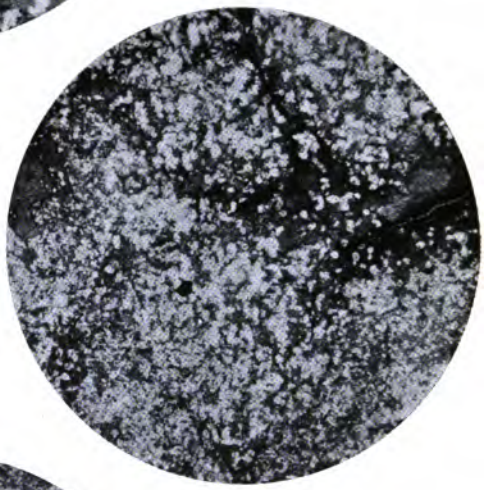


FIG. 11.—SCHIST.—With ill-defined foliation, consisting of a quartz mosaic and a base of margarodite, with patches of chlorite. The rock was probably originally a quartz porphyrite. Gormanston Road, west of the Gap.

+ Nicols. × 11 dia. [No. 79].

FIG. 12.—SCHISTOSE PORPHYRITE.—With a greatly altered plagioclase, which occupies most of the upper part of the slide. The lower part is a chloritic schist. Stubbs' Valley, near Queenstown.

+ Nicols. × 20 dia. [No. 119].

PHOTO—H. J. GRAYSON.

MOUNT LYELL SCHISTS.

but it has now been broken down into chloritic schist. It, therefore, represents an intermediate step between the porphyrites and the typical Lyell schists.

No. 117 is a schist from near the slates opposite the Mount Lyell converters, on a tributary of the creek that flows past Stubbs' lode. This rock is roughly schistose and consists of a green base, with angular, brecciated, grey inclusions. Microscopically the rock is seen to contain bands of green chlorite, which flow around the granular grey inclusions. The chlorite encloses magnetite crystals, and small bright spherules, which give a black cross under crossed nicols, and are no doubt some form of chalcedony. Patches of felspathic material can be recognized in the base. The rock in some respects resembles the last specimen described (No. 157), but it represents a still more altered phase of the porphyrites.

The felspathic schist (No. 119) from Stubbs' lode is formed from an altered porphyrite. It consists of a dark green base, which is roughly foliated and includes numerous phenocrysts of felspar. Examined microscopically, the rock is seen to have a definite foliation. Under crossed nicols the felspar phenocrysts are conspicuous, standing out of a holocrystalline re-crystallized base. The felspars are mostly plagioclase; and one figure (Pl. IV., fig. 12) gives symmetrical extinctions of 14° and 16°, so the species is albite. There are some quartz phenocrysts. The base is a holocrystalline mosaic of secondary quartz and felspar, with some white mica, grains of pyrite and magnetite, and of some indeterminable, feebly-polarizing material, which resembles the ordinary margarodite.

In Stubbs' Valley there is also a chloritic schist similar in composition to the last, but the whole rock (No. 161) appears green in colour, owing to the much greater abundance of chlorite, so that it has the aspect of a diabasic schist. Examined microscopically the rock shows the remains of felspar phenocrysts, which are in a more altered condition than in the last specimen. The microscopic evidence shows that this schist was probably originally a dyke of a rock much richer in the ferro-magnesian constituents than the adjacent porphyrites. (See Pl. V., fig. 13).

The breccia at the mouth of Stubbs' Lode Valley (No. 171) contains pebbles of the normal Queen River porphyrites, containing some untwinned felspar phenocrysts, as well as some which are certainly plagioclase, with straight extinctions. Some of the included phenocrysts have sharp, unbroken angles. The base consists of thin bands of quartz and chlorite, with lenticles of a felsitic material.

A banded porphyrite (No. 172) outcrops in the southern part of the Eastern Queen River. The rock is composed of bands of pinkish felspathic lenticles, in a foliated green base, which forms the bulk of the rock. The aspect is gneissoid, though even examination in the field suggests that the greenish part of the rock was not originally crystalline. Examined microscopically, the rock is seen to consist of phenocrysts of plagioclase, which are extremely altered. Pl. V., fig. 14, shows two broken plagioclase crystals, with one quartz phenocryst, which has been embayed by the ground mass. The crescentic ruins of a plagioclase crystal in a base of chloritic schist occurs in another part of the slide. Most of the original crystal has been destroyed, while the rest, though recognizable as plagioclase, has been altered by the development of irregularly-distributed crystals of zoisite. The base of the rock consists of a crushed felsitic mass, traversed by lines of chlorite. The whole of the ferro-magnesian mineral has been so decomposed that its original structure is indeterminable. The evidence of this rock, however, shows that there is probably no fundamental difference between this rock and the ordinary Lyell schist.

The massive banded porphyrites of the Eastern Queen River may be illustrated by No. 91. The bulk of the rock is a dark green schistose material, including big purple lenticles, some of which are 3 inches in length by a couple of inches in width. A section through part of one of the purple lenticles shows the rock in a comparatively unaltered form. Pl. V., fig. 15, shows one of the broken felspars, with sharp angles, included in a brown felsitic base, in which some grains and crystals of quartz and felspar have been developed. The felspars are mostly altered to aggregates of zoisite and chlorite or sericite. The rock has the

ordinary characters of a quartz felspar porphyrite, in which the base has been de-vitrified.

No. 95, from the huts near the Crown Lyell mine, has the aspect of an altered felspar porphyrite. It is somewhat similar to the rock found adjacent to Stubbs' lode, but has a less well-developed foliation. The rock consists of a dark green base, through which are scattered white felspar phenocrysts. The structure of the rock is that of a typical felspar porphyrite. Microscopic examination shows that the felspar is extremely altered, so that the crystals are barely recognizable except under crossed nicols, for the whole of the material has been re-crystallized. One or two crystals give recognizable extinction angles. One gives symmetrical extinctions of 11° and 12°, so it may be determined as albite. Pl. VI., Fig. 16, shows one of these extremely altered felspathic phenocrysts and a crystal of leucoxene, which has been formed from the alteration of ilmenite. No pyrites has been developed in this rock, and the original ilmenite has undergone the normal alteration to leucoxene.

No. 147, from the southern edge of the chief outcrop of the massive porphyrites on the Western Queen River, was collected north of a dyke cut through by the tramway on the western branch of the Queen River. The rock, examined in the field, is fresh, and is a fine-grained porphyrite, with a rough, granular fracture. The rock is mainly greyish-green in colour, containing inclusions of a pinkish felspar and dark bluish-green patches, formed from the original ferro-magnesian constituents. The rock, examined microscopically, appears unusually crowded with felspar phenocrysts, and has the aspect of the selvage of an intrusive porphyrite. The rock, however, has been crushed since its consolidation. Pl. VI., fig. 17, shows a band full of the felspar phenocrysts, each of which has been fractured and the fragments slightly displaced. Fluxion lines, due to pressure, occur around the felspars. The rest of the rock consists of a felsitic base, in which an imperfect foliation has been developed.

(D.)—AGE AND RELATIONS OF THE SCHISTS.

There have been three opposing views as to the relations of the Mount Lyell schists to the other rocks of the mining field. According to the first the schists are interbedded with the conglomerates; according to the second the schists are younger than the conglomerates; according to the third the schists are older than the conglomerates. The determination of this question is of primary importance to the future development of the field.

1. The relations of the schists to the conglomerates.

The first impression given by a casual study of the Mount Lyell mine is that the schists belong to the same series as the conglomerates. This view was naturally suggested by some of the clearest sections exposed in the field. Thus, beside the great pyrites body of Mount Lyell, the conglomerates underlie the ores as a footwall, while the schists overlie them as the hanging wall. The contact is also shown with great clearness in the Lyell Pioneer spur—the long spur of conglomerate north of the King Lyell claim. Looking at this spur from the opposite hill, the stratified conglomerates are seen to dip at an angle of 70° under the overlying schists, and are apparently conformable with them. A third typical exposure, suggesting the same relations between the schists and conglomerates, occurs on the Razorback (Figs. 1 and 2), where the conglomerates dip under the schists on the western side of the ridge at an angle of 60°; the junction is shown in an underlay winze put in to prospect a pyrites body. That the conglomerates and schists are interstratified is further suggested by the occurrence of bands of conglomerate to the west of the main conglomerate mass, and entirely surrounded by schists. They appear, moreover, to have the same strike and dip as the adjacent conglomerates. A still more striking argument in favour of interstratification is afforded by the section at the western foot of the haulage and in a branch from the No. 5 tunnel in the Mount Lyell mine. Both cases give apparently convincing evidence

FIG. 13.—FELSPATHIC SCHIST.—With a phenocryst of plagioclase. Stubbs' Valley.

Ord. Light. × 55 dia. [No. 161]

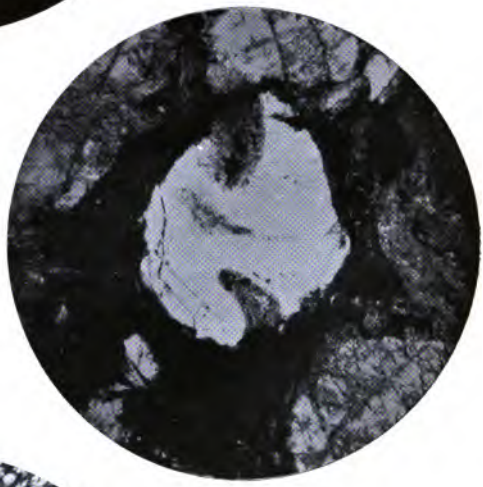


FIG. 14.—QUARTZ CRYSTAL.—Corroded and embayed by the ground mass. Stubbs' Valley. In porphyrite.

Ord. Light. × 55 dia. [No. 172].

FIG. 15.—BROKEN AND ALTERED PLAGIOCLASE CRYSTALS.—In the Mount Lyell Schists, eastern branch of the Queen River.

+ Nicols. × 37 dia. [No. 91].

PHOTO—H. J. GRAYSON.

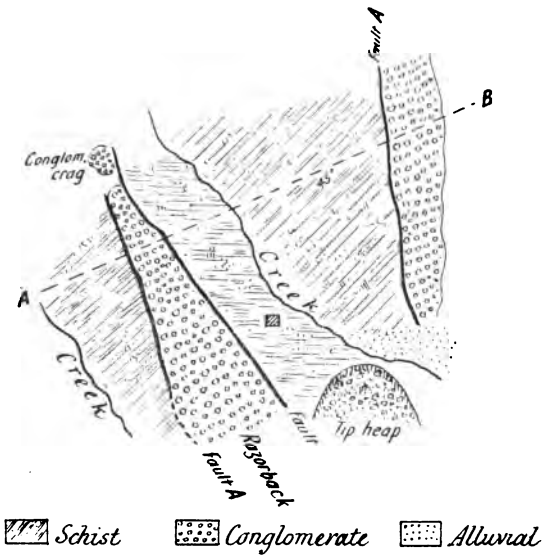


FIG. 1.

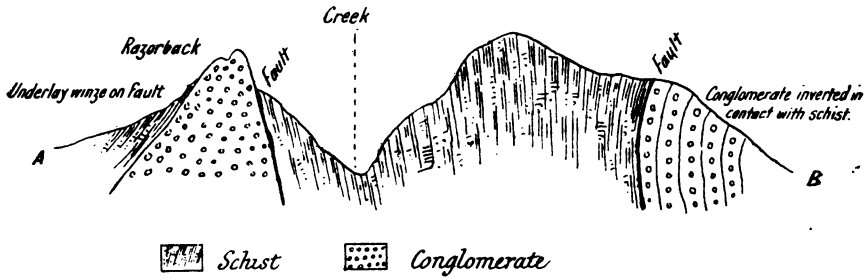


FIG. 2.

of the interstratification of the schists and conglomerates. Nevertheless, careful study of the relations of the conglomerates and schists shows that the superposition of the schists on the conglomerates always occurs close to powerful faults; and that where the beds remain in the order of their deposition the conglomerates always rest upon the schists. The schists and conglomerates have been faulted against one another along a great overthrust fault which runs north and south across the field. The superposition

of the schists and the cases of apparent interstratification are the results of geological accidents, and do not imply their later age. The evidence is conclusive that the conglomerates are younger than the schists.

Thus, in a general view across the field, as for example looking southward from the conglomerate crags above North Lyell, the schists may be recognized as the basal rock of the area, and Mount Owen as a great block of conglomerate resting upon an underlying foundation of schist. Moreover, as we look around the whole field, we may notice that, as a rule, the conglomerates form the mountain tops, while the schists are exposed on the flanks of the mountains and along the valleys. Speaking generally, the conglomerates form the high land, while the schists form the lower land. It is only locally, along the Great Fault of Mount Lyell, that the reverse obtains. Detailed study of the structure of any part of the field confirms the impression left by a general view. Thus, for example, Mount Owen consists of a great faulted block of conglomerate resting upon schists, which are exposed at many points on the mountain slopes, and occasionally on or near the crest. The schists always outcrop below the conglomerates, and usually below the basal members of the conglomerate series.

Still more conclusive evidence, however, is yielded by the abundance of pebbles of schist in the conglomerates. The presence of these pebbles was noted by Montgomery, who described the conglomerates as composed of micaceous schist and quartzite.* If, therefore, the conglomerates all belong to one geological system, then the schists must clearly be the older. In some places it is difficult to find in the conglomerates any pebbles, other than quartz, for all the softer rocks have been destroyed ; but in various localities, as at the head of Conglomerate Creek, to the north of the summit of Mount Owen, in the red quartzites near the summit of Mount Lyell, at Gormanston Gap, and in the road section between the Linda township and the Lyell Blocks mine, abundant schist pebbles occur in the conglomerates.

* Montgomery, A., "Glacial Action in Tasmania," Proc. Roy. Soc., Tasmania, 1893 (1894), p. 159.

Chapter VII.—The Non-schistose Igneous Rocks of Mount Lyell.

Igneous rocks occur at intervals along the Queen River, from Lynchford northward to the Sedgwick Gap. They are well exposed on the hill slopes to the south-west of Mount Owen, and they extend along the eastern and western branches of the Queen River, north of Queenstown. The rocks here have been described as syenites, and some of the best preserved, when examined in hand specimens, appear to be coarse-grained plutonic rocks, composed of a pink felspar and a green ferro-magnesian mineral. The name syenite was, therefore, naturally applied to them. These rocks are bounded to the east by a series of felspathic schists, which are succeeded to the east by the typical schist of the Mount Lyell field. In places, moreover, the igneous rocks contain some intrusions of quartz porphyrite, which are well shown westward of the Crown Lyell mine, towards M'Cusick's Creek, a tributary of the Queen River.

At first I was tempted to believe that the "syenites" were intrusive igneous rocks, intruded after the formation of the conglomerates of the West Coast Range; and that it was their intrusion which supplied the power and the heat, that caused the great faults and formed the ores. In this view I was somewhat strengthened by being unable to find in the conglomerates any of the typical pebbles of these apparent syenites. Microscopic evidence, however, renders it probable (pp. 56-59) that the supposed plutonic rocks are part of the same primitive series as the Mount Lyell schists, and that they are pre-Silurian in age. The evidence for this opinion is not as conclusive as I should like it to be, because I failed to find any sections which placed the relation of the Silurian and the igneous rocks beyond doubt. In M'Cusick's Creek, where the two rocks are in contact, the Silurians do not show any contact

metamorphism; but the junction is faulted, so that, though the beds might have been altered at a greater depth, the altered bands may have been removed by the fault action. However, in M'Cusick's Creek there is a conglomerate interbedded with the Silurian rocks; it has the characters of a crushed basal conglomerate; and it was full of pebbles of the igneous rocks. A little further away from the contact is a bed of coarse-grained sandstone, interbedded with the Silurian rocks, and it is largely made up of the igneous rocks.

The microscopic structure of two of these rocks is as follows:—

One, from M'Cusick's Creek, just to the west of the western border of the Queen River porphyrites (No. 150), is a clay slate breccia composed of pebbles of quartz, clay slate, schist, and porphyrite (Pl. VI., fig. 18). The whole rock has been crushed and foliated by pressure. Some of the schist fragments have been broken and slightly separated. The microscopic structure of the rock proves that the breccia was formed later than the time of the porphyrites, fragments of which occur in it.

Some coarse sandstone (No. 151), which is interbedded with the slates a little to the west of the last specimen, occurs close by the western boundary of the Mount Lyell reserve leases. The rock is greyish-green in colour, and contains abundant chloritic material. The rock is seen, when examined microscopically, to consist mainly of angular and rounded quartz grains, set in a fine-grained argillaceous paste, which polarizes feebly. The rock contains streaks and flakes of chlorite, and here and there some short bands of calcite. The rock is no doubt a member of the Silurian series, and was an ordinary deposit laid down upon the flanks of the porphyrites.

The microscopic evidence, therefore, renders it almost certain that the Silurian rocks are younger than the Lyell schists. But the evidence is not quite conclusive. According to Officer, Balfour, and Hogg, the Mount Lyell schists are even Archean. But one or two features suggest the possibility of these schists being later than the Silurian rocks; thus some bands of slate occur in

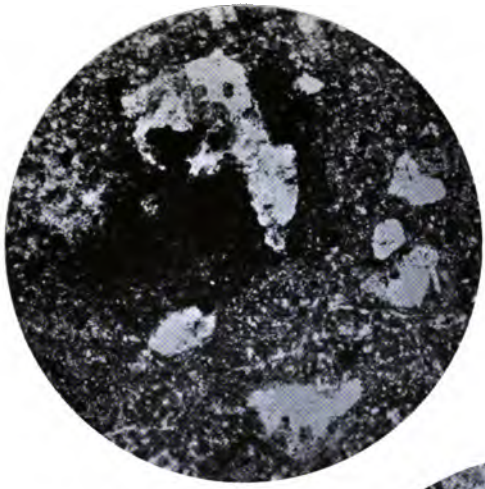


FIG. 16.—SCHISTOSE FELSPAR-PORPHYRITE. — With large crystal of leucoxene. Near the Crown Lyell Mine.

+ Nicols. × 11 dia. [No. 95]

FIG 17.—SCHISTOSE QUARTZ-FELSPAR-PORPHYRITE.—With broken felspar phenocrysts. Western branch of the Queen River.

+ Nicols. × 37 dia. [No. 147].

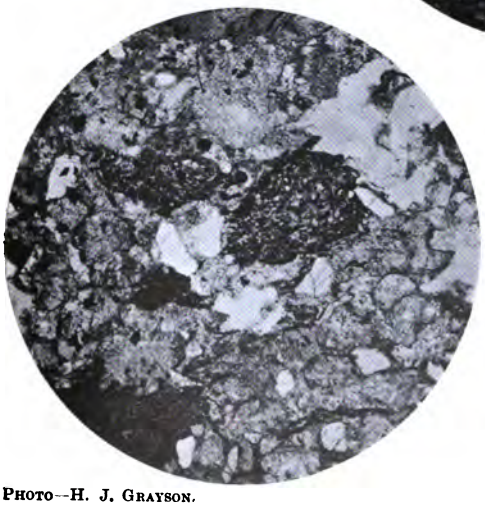


FIG. 18.—BRECCIATED CLAY SLATE.—With inclusions of the Lyell schist, McCusick's Creek.

+ Nicols. × 12 dia. [No. 150].

PHOTO—H. J. GRAYSON.

MOUNT LYELL SCHISTS AND SILURIAN BRECCIATED SLATE.

the igneous rocks to the east of the west branch of the Queen River, opposite M'Cusick's Creek. I was at first inclined to regard them as having been torn from their associated rocks and brought up included in the igneous series. They, however, showed no signs of having been baked, and probably they have been let into the igneous series by faults.

The question of the relative age of the Silurian rocks and the Lyell schists had, however, no direct bearing on the economic geology of the Mount Lyell field, so I did not devote to it the time necessary to its determination. These two rock series are faulted together on the only clear junctions that I saw. The conglomerates on the M'Cusick Creek would conclusively prove that the Silurian deposits were laid down upon the older Lyell schists, unless, as is conceivable, the conglomerates were formed by the faulting.

The rocks at the mining fields of Mount Darwin* and Mount Read,† which appear to continue the Lyell schists to the south and north, are regarded by Twelvetrees and Petterd as either Silurian or pre-Silurian. This opinion is in agreement with my impression as to the pre-Silurian age of the Mount Lyell schists.

The available evidence, therefore, renders it probable that the diabase porphyrites of the Queen River are part of a pre-Silurian igneous series, of which some of the rocks on the margin were quartz porphyrites, and have been altered into the Mount Lyell schists.‡

* Twelvetrees, W. H., "Report on the Mineral Districts of Mounts Huxley, Jukes, and Darwin," Launceston, 1900, Mines Dept., Tasmania, p. 4.

† Twelvetrees, W. H., and Petterd, W. F., "On the Felsites and Associated Rocks of Mount Read and Vicinity," Proc. Roy. Soc., Tasmania, 1898–9 (1900), pp. 36, 42.

‡ Mr. Twelvetrees has come to the conclusion that the quartz porphyry of Mount Darwin, 12 miles south of Gormanston, also passes gradually into the schists, which are, no doubt, the southward continuation of the Mount Lyell schists.—Twelvetrees, W. H., "Report on . . . . Mounts Huxley, Jukes, and Darwin," Mines Department, Hobart, 1900, p. 4.

The non-schistose igneous rocks of the Queen River consist of two main types:—

1. A series of coarse diabase porphyrites of a massive structure, usually with a dark green base and pink porphyritic inclusions.

2. Some intrusive dykes of diabase.

The massive porphyritic rocks have been referred to previously as augite syenites. But this name is unsuitable for those which I have examined microscopically. Their structure is certainly that of porphyrites, and is not granitic. The nature of the ferromagnesian mineral is indeterminable in the specimens that I have examined. But the typical felspars belong to the andesine-oligoclase series. The best name for this group of rocks is, it seems to me, diabase-porphyrites. Some of them may have been originally syenite-porphyrites.

These rocks are well developed along the Western Queen River, where they are represented by specimen No. 155. This rock is massive in texture. It has a dark green base, full of pink felspathic inclusions; in places the base also is stained pink. Examined microscopically, the rock is porphyritic with a holocrystalline base. The phenocrysts consist mainly of felspar with a little quartz. They are often embayed by the ground mass as well as broken into fragments, which are slightly separated. Most of the phenocrysts are aggregates of plagioclase (Pl. VII., fig. 19), but a few of the felspars are simply twinned. There are occasional quartz phenocrysts and some large single crystals of felspar. Scattered through the rock are aggregates of chlorite and of a bright yellow, transparent, highly refractive variety of epidote. Some of the chlorite contains abundant crystals of magnetite. The base is holocrystalline, and consists of a confused mixture of quartz, felspar, and white mica. The quartz and felspars are in very confused intergrowths. The extinction direction of the felspars is not easily determined; one or two of the microliths give extinctions up to 36°, as in anorthite.

Specimen No. 92, from the Eastern Queen River, is a dark green rock with felspathic phenocrysts, with a compact base of a brown to sometimes dark green colour. There are some phenocrysts of

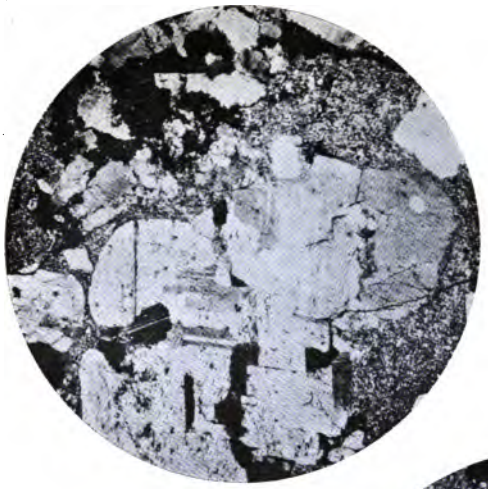


FIG. 19.—PLAGIOCLASE AGGREGATES.—In the Queen River porphyrites. Western branch of the Queen River.

+ Nicols. × 11 dia. [No. 155].

FIG. 20.—AN OLIGOCLASE-ANDESINE PHENOCRYST.—In a base of quartz, chlorite, epidote and magnetite. Eastern branch of the Queen River.

+ Nicols. × 11 dia. [No. 92].

FIG. 21.—PLAGIOCLASE PHENOCRYSTS.—In an altered felsitic base. Eastern branch of the Queen River.

+ Nicols. × 32 dia, [No. 177].

PHOTO—H. J. GRAYSON.

QUEEN RIVER PORPHYRITES.

green chlorite. Plagioclase is the predominant felspar; there are some simply twinned crystals, which may be orthoclase. Measurements of one crystal (Pl. VII., fig. 20) show by its symmetrical extinction that it is oligoclase-andesine. The original ferro-magnesian material has now been so altered as to be unrecognizable; it has been reduced to a mixture of quartz, chlorite, epidote, and magnetite. The chlorite has the bright prussian blue colours of pennine. Some of the plagioclase is intergrown with the chlorite aggregates.

No. 177, also from the valley of the Eastern Queen River, has superficially a somewhat purple tint. It consists of a porphyrite with pink felspars included in a green to pinkish base. Examined microscopically, the porphyritic felspars generally show plagioclase twinning. Scattered through the rock are bars and crystals of magnetite. The base is de-vitrified and felsitic. The chlorite is secondary, as in the two previously described specimens, and occurs in very thin, loosely arranged aggregates. The rock, there can be little doubt, is a de-vitrified porphyrite (Pl. VII., fig. 21).

No. 179 is from the upper part of the Eastern Queen River, where it can be seen as a dyke, cutting through some schists. It is a red porphyrite, with, when cut, much the colour of Egyptian porphyry. The original ferro-magnesian mineral is represented by dark green or or black inclusions. An analysis of this rock is given on p. 159 (No. II., 2). Examined microscopically, the rock is seen to be porphyritic, with abundant phenocrysts of quartz and plagioclase (Pl. VIII., fig. 22), but with some felspars which are simply twinned. The chloritic aggregates are abundant, and contain much magnetite and white mica. The original presence of ilmenite is indicated by the abundance of leucoxene. The base is a granular quartz-felspar mosaic. The bulk of this felspar is plagioclase. The rock has been slightly crushed, though this incipient foliation is barely recognizable in hand specimens. White mica has been abundantly developed along the lines of crushing.

No. 188, from lease 3,582, on the western branch of the Queen River, is also a quartz-felspar porphyrite, with the phenocrysts less broken and more regularly idiomorphic than in the previous

specimens. Some of the phenocrysts are dusty, with minute granules of epidote, and they include some chlorites. The chlorite often gives purplish polarization colours, and some of it is shown by its form to have been formed by the alteration of biotite. The base is holocrystalline and embays the phenocrysts. Some of the plagioclase crystals belong to the oligoclase series.

Basic Dykes in the Schist and Porphyrite Series.

A diabasic dyke occurs adjacent to Stubbs' lode. The rock (Nos. 174 and 180) is massive, of a dark green colour, and is plentifully speckled with minute crystals of yellow pyrites. The rest of the pyrites is in small granules scattered freely through the rock. An imperfect foliation becomes apparent on weathered surfaces. The field evidence shows that the rock was a dyke, cutting through the adjacent schists. Examined microscopically (Pl. VIII., figs. 23, 24), the bulk of the rock is seen to consist of chlorite, which is developed in places as aggregates of well-defined flakes, and elsewhere in thin scales. Under crossed nicols the chlorite shows prussian blue interference colours. Where the chlorite is most abundant it occurs in closely-packed, rounded or angular patches, which are separated by lines of an opaque material, which is white by reflected light. This material is developed, along fracture lines, through the chlorite. The rest of the rock consists of some coarse aggregates of quartz, which is apparently always secondary, of grey felsitic areas, and some patches of the brightly polarizing margarodite material. The rock is too altered to admit of the determination of the mineral from which the chlorite has been developed. It is, no doubt, a diabasic alteration of a dyke rock, which was more basic than the Queen River porphyrites.

A decomposed, basic dyke crosses the Gormanston road, near the sharp bend west of the Gormanston Gap. The rock (No. 78) is shown by its field relations to be an intrusive dyke. It is of a dark brownish colour. The fractures through it contain many minute flakes of mica. Microscopically the most conspicuous features of the

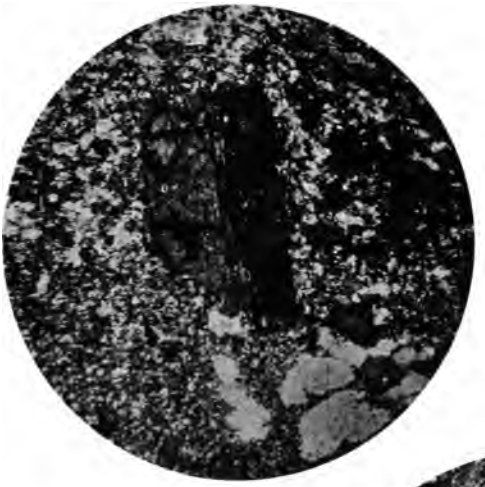


FIG. 22.—PLAGIOCLASE PHENOCRYST.—In a base of quartz-felspar mosaic. Porphyrite dyke on the eastern branch of the Queen River.

+ Nicols. × 32 dia. [No. 179].

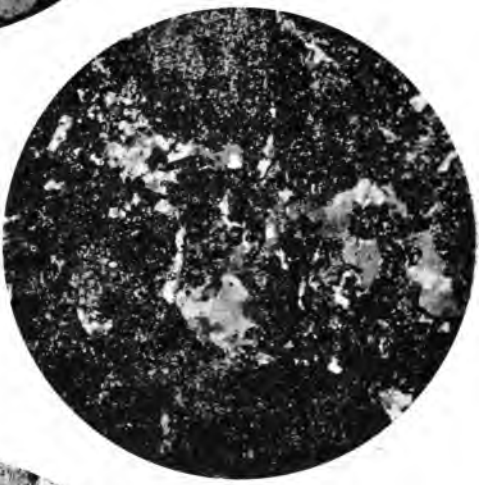


FIG. 23.—DIABASE.—Consisting of an aggregate of chlorite, margarodite and quartz, with small crystals of pyrites. From a dyke beside Stubbs' Lode.

+ Nicols. × 14 dia. [No. 174].

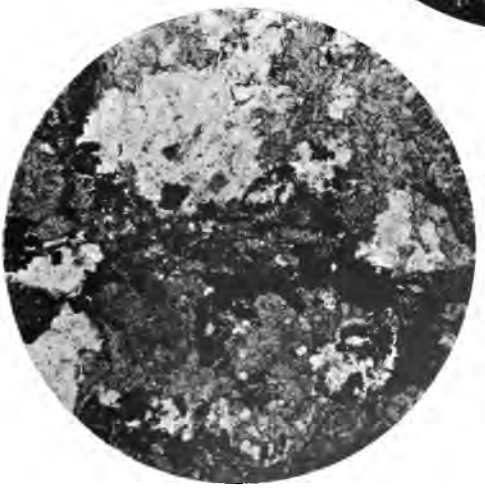


FIG. 24.—The same, with areas of margarodite, chlorite and pyrites.

Ord. Light. × 31 dia. [No. 174].

PORPHYRITE AND DIABASE DYKE ROCKS.

PHOTO—H. J. GRAYSON.

rock are the abundant crystals of brown mica; they are set in a base, most of which is stained limonite yellow and polarizes feebly. There are the remains of some lath-shaped plagioclase crystals, which have been intensely altered. Quartz was apparently absent from the original rock. In the absence of evidence as to the other constituents, the rock can only be determined as a basic mica trap or a kersantite.

Chapter VIII.—The Silurian Rocks.

The Silurian rocks are of secondary importance in the history of the mining field; their main value geologically is that they determine the ages of the other rocks of the area. The Silurian rocks in the Mount Lyell area occur in two belts, which are apparently disconnected. The first lies east beyond the King River, where there is a wide expanse of Silurian rocks extending eastward to the foot of what is called the central plateau of Tasmania. The second area of Silurian rocks occurs near Queenstown, and thence westward towards Strahan and Zeehan. These rocks consist of beds of slates, shales, sandstones, and limestones. Excellent sections are exposed by the flux quarries at Queenstown, in beds of sandstone and limestone with a strike of about 107°. Silurian rocks are also exposed along the railway to the smelters; the rocks are more decomposed, and the sections poorer. Opposite smelter No. 1, and north of the pumping station, is a series of slates with a strike of 140°; they are faulted to the north, against the igneous rocks and schists.

The Silurian rocks extend up the western branch of the Queen River as far as the second bridge. Along the right bank of the West Queen River is a series of sandstone ridges resting upon igneous rocks; and south of the Queenstown rifle range are sandstones and slates, which vary in strike from 95° to 105°, and form a series of hills, up which the road to Strahan rises on to the Madame Howard Plains. These rocks occupy the south-western part of the northern half of the reserve leases of Mount Lyell, and they end abruptly to the north, along a fault which brings them against the schists and igneous rocks. At the head of M'Cusick's Creek, one of the tributaries of the western branch of the Queen River, the slates outcrop along the western edge of the Mount Lyell reserve leases. Here they are faulted against the igneous rocks of the Queen River, the two series being separated by a band of fault breccia.

In the centre of the northern half of the Reserve Lease there are some small scattered occurrences of the Silurian rocks. In the tributary opposite M'Cusick's Creek, on the left bank of the West Queen River, there are a few acres covered with sandstone debris; and in the next creek to the south, a 6-foot band of clay slate is included in the igneous rocks. Two further bands of clay slate occur in the igneous rocks near Harris's alluvial claim, along a creek that flows into the East Queen River opposite an old forge a little over half a mile from the southern end of the East Queen Gorge.

The age of these rocks is somewhat uncertain. They may be an extension of the Silurian rocks exposed near Zeehan, or perhaps of the Ordovician rocks of the Gordon River. The sandstones are known as the Queen River sandstones, and have generally been identified as Silurian (that is, as "Upper Silurian").

This view was based on the discovery by Moore in 1884 of some fossiliferous sandstones on the King River. But as there is a band of fossiliferous sandstones in the overlying conglomerate series, it is possible that Moore's specimens came from that horizon. There are, however, some fossiliferous sandstones to the north-west of Queenstown; I collected some obscure fossils on lease No. 1834/93M, but the specimens were not such as would induce me to put much faith in any opinion founded on them as to their age.

The following fossils have been determined by Johnston* from the specimens collected by Moore:—

Spirifera crispa.
S. plicatella.
Orthis flabellum.
O. elegantula.

But in view of the unsatisfactory nature of the specimens on which these identifications were based, it might not be safe to express any positive opinion as to their exact age, even if we knew the

* Johnston, "Geology of Tasmania," 1888, p. 64.

position whence Moore's fossils were derived.* Some graptolites have been found in western Tasmania in these "Silurian" rocks; some specimens were collected on the road from Strahan to Queenstown and others in Zeehan, but their evidence is inconclusive.† Mr. Twelvetrees, in his "Outlines of the Geology of Tasmania," includes most of the Mount Lyell beds in a group which he identifies as middle and upper Silurian; he places the schists, conglomerates, and limestones of Mount Lyell as the lowest members of this group. Next above these rocks he places the brachiopod sandstones of the Queen River, while the quartz porphyries and felsites of Mount Owen are its uppermost division.

We may safely regard the Queenstown sandstones and limestones as either of Silurian or Ordovician age. True Silurian rocks certainly occur at Zeehan, 16 miles to the north-west of Queenstown.

Economically the most important rock in the Silurian beds is the limestone used as a flux in the smelting operations at Queenstown.

The limestone of the flux quarry immediately underlies a thick bed of quartzite, also used as a flux. The strike and dip of both beds are approximately parallel, the dip in both cases being almost vertical. The width of the limestone is 450 feet, and it has been followed for 650 feet along the strike. It has been quarried to a vertical depth of 130 feet. The limestone, examined microscopically, is saccharoidal, and is composed of a mosaic of dirty grey twinned calcite grains. The less pure variety contains a little dolomite. Between the calcite grains is some very fine-grained dust, which includes some magnetite; and a little of the same material is included in some of the calcite grains. The rock has been so altered that identifiable fossils are hardly to be expected;

* These brachiopods, according to Mr. Twelvetrees, were found in the creek at Gormanston, and apparently not *in situ*.—Twelvetrees, W. H., "Report on Mounts Huxley, Jukes, and Darwin," Mines Department, Hobart, 1900, p. 4.

† Hall, T. S., "Evidence of Graptolites in Tasmania," Rep. Sec. Mines, Tasmania, 1901 (1902), pp. 170, 171.

but it contains some fragments, which have not been rendered saccharoidal and still show distinct traces of organic origin. They are traversed by canals, but are not sufficiently well preserved for identification. They occur, however, in sufficient abundance to suggest that the limestone was mainly built up of organic material. The best-preserved fossil remains occur in a specimen, which I selected in the quarry, as it had a banded structure of apparently organic origin. Two analyses of the limestones by the Mount Lyell Company are as follows:—*

Limestone.

	Grey.	Black.
Silica	10·92	3·26
Iron oxide	·57	·85
Alumina	2·88	·86
Carbonate of lime ..	83·40	95·10
Carbonate of magnesia ..	3·00	trace

The black limestone is pure, while the grey limestone is slightly dolomitic.

* Rep. Sec. Mines, Tasmania, 1901–2 (1902), p. cxlix.

Chapter IX.—The Devonian Conglomerates.

The conglomerates, that are such conspicuous features in the geology of the Mount Lyell field, have been divided by most writers between two distinct series—an old series, interstratified with the schists and now standing almost vertically, and a younger series, of which the beds are still comparatively horizontal, and cap the mountains of the West Coast Range. This view has been advanced by Montgomery, Officer, and Cundy, and it received perhaps its most definite expression in Twelvetrees' "Sketch of the Geology of Tasmania," pp. 3 and 6. Peters and Daly, on the other hand, were bound to include all the conglomerates in one series, in consequence of their view that all the rocks of the Mount Lyell field belong to the Silurian system. Mr. Batchelor has also come to the conclusion that the conglomerates are all part of the same series.

The arguments in favour of there being two distinct conglomerates are the fact that the lowest conglomerates exposed in the field are tilted at a high angle, and dip westward under the schists; whereas the conglomerates that form the higher parts of Mounts Owen and Lyell are more horizontal, and occur only at higher levels and obviously overlie the schists.

The evidence is, however, in my opinion, conclusive that, with the exception of a few local crush-conglomerates, there is only one series of conglomerates on the Mount Lyell field. The supposed Silurian conglomerates associated with the ore deposits, generally belong to the lower part of the conglomerate series; but they have precisely the same lithological characters as the conglomerates that cap the mountains. Their high dip is simply due to the earth movements by which they have been brought against the schists.

The view that the conglomerates are older than the schists, which has been held till recently, is untenable. as has already

been shown (pp. 50-52). Many sections on the field, however, appear to support it. Thus the conglomerates form the foot-wall of the main ore masses; and in various places the conglomerates appear to underlie the schists conformably. Thus at the lower end of the Lyell Pioneer Spur, east of the Razorback, the conglomerates dip westward in apparent conformity with the overlying schists. More careful examination shows that this apparent superposition is due to an overthrust fault, the junction between the schists and the conglomerates being a fault. At other localities (as in Fig. 3), where the relations of the beds are as clearly shown, the conglomerates overlie the schists. Thus the waterfall in Conglomerate Creek occurs where the stream rushes over a high cliff of the red quartzites, which form the lowest members of the conglomerate series. The schists occur immediately below the quartzite, and also dip to the east at a high angle. The schists form the western end of the spur, which, at the lower end is capped by some white quartzite and conglomerate; this material, however, may possibly not be *in situ*, but be only the decomposed remains of a former outcrop (see Fig. 4).

Further evidence that the schists underlie the conglomerates is given by the fact that, taking the field as a whole, the schists occur on the lower slopes of the hills and in the valleys, while the conglomerates crown the mountain summits, and tend to occur along the higher parts of the hill slopes; the schists crop out from below the conglomerates all round the flanks of the mountains.

The conglomerate series may be divided into three parts. Their sequence is best shown on the northern face of Mount Owen, which has been bared for inspection by glacial action (Fig. 5). The lowest division is a series of red quartzites, with some bands of conglomerate, which form the lower part of the north-western spur of Mount Owen. These red beds are covered by a white quartzite, which passes up into the second main division, some beds of very coarse puddingstone. The rest of the conglomerate series consists of coarse-grained quartzites, sandstones, and conglomerates. Here and there in the midst of this series are thin layers of green shale, but they appear to be always thin and local.

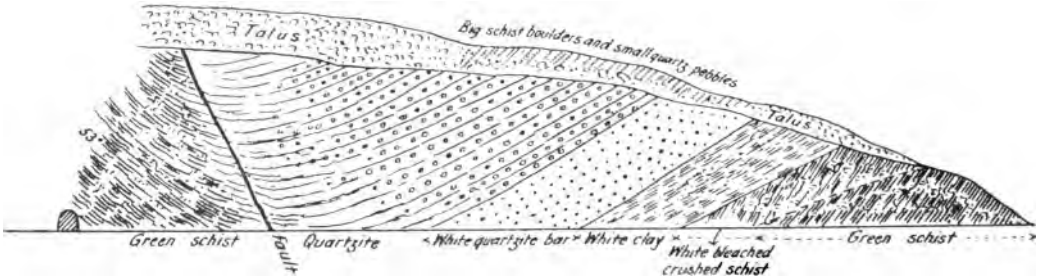


FIG. 3.

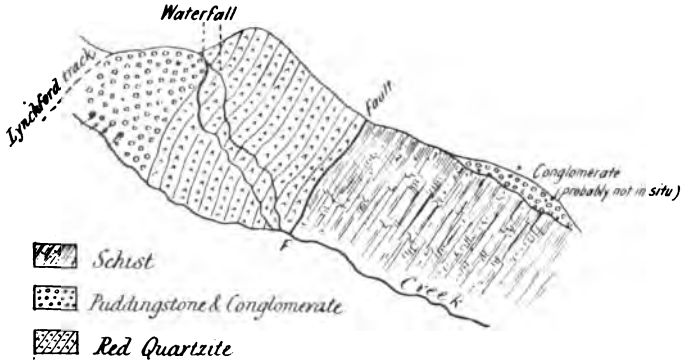
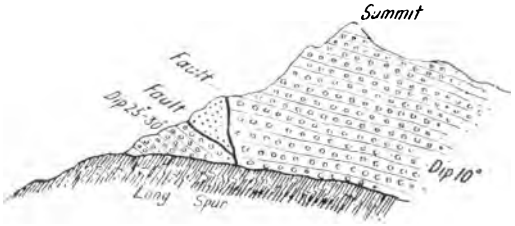


FIG. 4.



Mt Owen from the crags south of the haulage.

FIG. 5.

These three divisions can be recognized throughout the field. The red quartzites are naturally the most conspicuous, and their presence has been regarded as an indication of proximity to a copper-bearing lode. But this association was only accidental, and due to the fact that, as the red quartzites are the lowest members of the series, they naturally most often occur next the schists.

The distribution of the red quartzites is important, because they generally indicate the proximity of the underlying schists. They occur at the height of 2,350 feet on the western end of Mount Lyell, where the track to the Sedgwick Valley crosses the great buttress of conglomerate. They just come to the surface along the creeks going southwards from North Lyell towards the head of Brown's Creek; they appear on the road between the Lyell blocks and the Linda township; they are found on the Razorback and all along the contact between the conglomerates and schists in the neighbourhood of the Mount Lyell mine; they are exposed, resting directly on the schists, at the Gormanston Gap; and they appear in most of the valleys on the western side of Mount Owen, which have cut their way along faults down to the level of the schists. Red quartzites also occur upon Mount Lyell to the east and south of the summit; their presence in both cases no doubt indicating that the underlying schists are but little below the surface.

The coarse puddingstone is a less easily recognized division, but it can be traced through the field at some little height above the red quartzites. The quartz boulders in this puddingstone are often of great size, specimens being found a couple of feet in diameter. I saw no trace of ice action in these conglomerates, and the matrix of the pebbles is coarse and gritty. The size of the boulders, therefore, indicates that the beds have been formed by powerful current action in close proximity to the source of supply. The large boulders are very irregular in form; and whereas the pebbles in many of the finer-grained beds of conglomerate have the flattened, bun-like form typical of those on sea beaches, the form of the puddingstone boulders is more like that of the gravels of torrential rivers and coarse delta gravels. The conglomerates as a whole are composed of quartz. The great majority of the pebbles are a

milky white vein quartz, but they include also specimens of granular quartzites. There is some black quartzite or jasperoid, which is similar in appearance to the black jasperoids, which are extensively developed in the Heathcotian rocks of Victoria. In places there is an abundance of schist pebbles. Montgomery recorded the occurrence of micaceous schists; but the commonest schist pebbles which I noticed resemble the harder types of the Mount Lyell schist.

The conglomerates no doubt once extended as a continuous sheet across the Mount Lyell field, but owing to fault action and denudation they have been reduced to a series of detached blocks. The two chief masses form the summits of Mount Lyell and Mount Owen. Both of these mountains consist of a sheet of conglomerate protecting a foundation of the softer underlying schists. Mount Lyell forms a long ridge three miles in length and about one mile in width. Practically the whole of the summit is formed of the conglomerate, but outcrops of the schists occur at intervals along the ridge and below its crest. The schists are seen at the northern foot of the mountain, resting against the conglomerates, which are there dipping northward at as much as 60°. On the main ridge of Mount Lyell the conglomerates generally dip from 10° to 15°, and the crest of the mountain is a broad ridge, which has been described as a plateau. On the south of the ridge the conglomerates have been let down along a fault, forming a long platform, the southern edge of which appears to be due to a second and parallel fault. At the eastern end of Mount Lyell the conglomerates have been uptilted along a meridional fault, and lie at a high angle with a steep dip to the west, while most of the rocks in the mountain have an eastern and western strike, with a dip to the north.

A great lateral displacement of the conglomerates has been caused by the chief of the faults cutting across Mount Lyell from east to west. To the north of this fault the conglomerates occur further to the west, forming the great buttress overhanging the Queen Valley. At the eastern end of Mount Lyell the conglomerates occur farthest to the east, on the southern side of this fault; there they form some undulating, timbered, glaciated hills.

Mount Owen is a peak rather than a ridge like Mount Lyell. It consists of a thick sheet of conglomerate broken up into a series of blocks by fault action. The beds of the different blocks can be correlated by the red quartzites. The best sections showing the structure of the mountain are on the western slopes of the mountain, in the valley of Conglomerate Creek and its tributaries (Fig. 6). Three prominent spurs run out to the west; each spur has a steep fault face to the north and a dip slope to the south. The schists are exposed here and there at the foot of the fault scarp, and as the schists also occur at the foot of the eastern face of

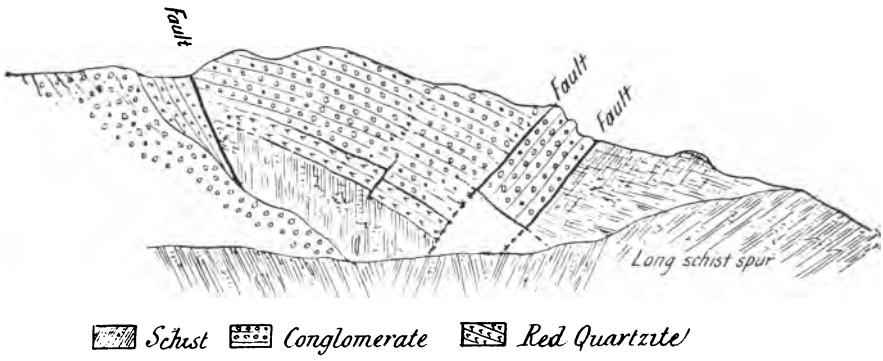


FIG. 6.

the mountain, there can be no little doubt that they are continued beneath the conglomerates, under the whole of Mount Owen.

The conglomerates are shown in the same relation to the schists at the western end of the Linda Valley, where three conglomerate ridges project as spurs from the ridge of schists which connects Mount Lyell and Mount Owen. The northern ridge is the longest; it runs down the southern boundary of Brown's Creek from North Lyell to the Linda township. It may be called the North Lyell Spur. To the south of it by the valley, including Karlson's Flat, is a conglomerate spur, which may be called the Pioneer Spur. It is bounded to the south by the valley containing the deposits worked for alluvial gold on the King Lyell lease. To the south of this

valley is the boss of conglomerate on which stands the mine offices of the Mount Lyell Mining Company.

The remaining important outcrops of the conglomerates occur along a line of crags, each of which consists of conglomerate completely surrounded by schists, into which they have been let down by faults. The Razorback is the most southerly of these outliers; it rises to the north of the Haulage. Further north, overhanging the township of North Lyell, is a crag of conglomerate in which the beds are in places vertical and have a strike varying from 28° east of north to 5° east of north. This North Lyell crag consists of puddingstone and basal quartzites, both of which contain an abundant series of quartz veins.

As a rule the conglomerates contain no ores or quartz veins; but the latter occur where the rocks have been cracked near the faults. In places where faults have brought the conglomerates against the schists, the conglomerates are seamed by a network of quartz veins, and include crystals of marcasite and pyrites.

The total thickness of the conglomerates is unknown. They have been greatly denuded, and the top layers have been removed. The maximum thickness of the existing remnants of the conglomerate sheet is probably from 1,600 to 1,800 feet. This estimate is based upon the thickness of the beds exposed on the northern face of Mount Owen. The frequent repetition of beds by fault action exaggerates their apparent thickness.

Age of the Conglomerates.

The conglomerates are often spoken of as Devonian, a proceeding which is useful, as it emphasizes the unity of the whole conglomerate series of the Mount Lyell field. The palæontological evidence, however, is insufficient. Some fossils occur in a band which is widely distributed throughout the field. It is shown on the hill west of Gormanston between the mine manager's house and the offices of the Mount Lyell Mining Company; the beds there strike 295° and dip 15° to 20° to the south-west. The fossils here a

FIG. 25. — DIABASE. — From another specimen from Stubbs' Valley, with patches of margarodite surrounded by bands of chlorite and pyrites.

+ Nicols. × 55 dia. [No. 180].

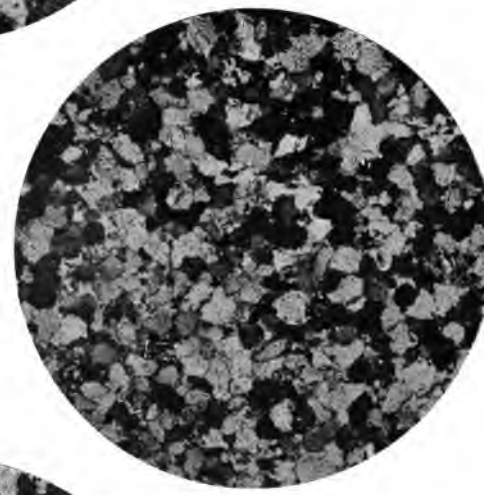


FIG. 26.—QUARTZITE.—From the conglomerate series, shewing strain polarization effects in the grains. From the surface, beside the Mount Lyell Mine.

+ Nicols. × 14 dia. [No. 193].

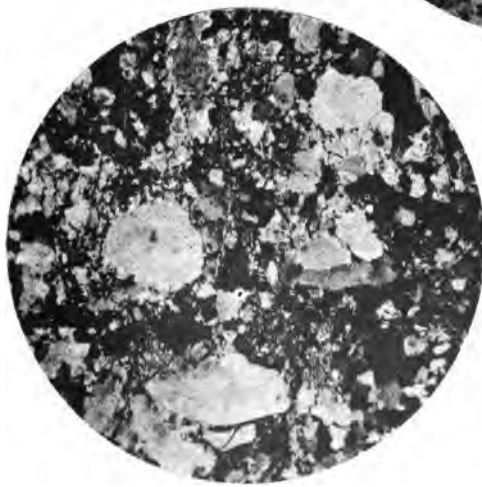


FIG. 27.—QUARTZITE.—With the base re-crystallized as a fine quartz mosaic, and chloritic patches derived from the Lyell schists, Main Tunnel, No. 5 level.

+ Nicols. × 29 dia. [No. 194].

PHOTO—H. J. GRAYSON.

DIABASE
AND
CONGLOMERATE SERIES.

triangular in section, with sharp edges. Many of these quartz grains show strain polarization effects, and the concave faces of some of the grains suggest that they have been crushed since their inclusion in the rock. The rock contains a few fragments of chloritic schist, and there are some dark patches of oxidized pyrites; also a few thin veins of secondary quartz mosaic.

The rock (No. 194) 50 feet north of the pyrites tongue at the main tunnel at No. 5 level, is a fine-grained purplish-brown quartzite, with a few pebbles of clear quartz. The microscope shows that the rock has undergone great changes (Pl. IX., fig. 27). Most of the quartz grains have been broken down to a secondary quartz mosaic, and each grain has a different optical orientation. The rock is traversed by one line, where the constituents have been crushed and have moved along a line of flow. Several included fragments of schist have been cut across by this fault plane. In one part of the slide a quartz pebble has been faulted across, and projects into a band of schist, which has been completely crushed into mylonite. Under crossed nicols the quartz pebble breaks up into an aggregate of quartz grains surrounded by a quartz mosaic. In the paste of the rock there are some chloritic patches, which have probably been derived from inclusions of crushed schists.

A specimen (No. 195) from the same tunnel, but 10 feet north of the pyrites tongue, is a purplish-brown, gritty sandstone; it is composed of quartz and schist, in which the quartz grains are normal, and the schist fragments have been crushed, and their outlines altered by the quartz grains having been forced into them. There are some triangular patches of chloritic material and abundant grains of black ore dusted through the rock.

No. 199 is a dark grey quartzite with finely disseminated pyrites and a few quartz grains with ill-defined boundaries. It comes from the contact of the pyrites tongue with the horse of schist. This rock consists of quartz in fine bands, which, examined under a high power, are seen to be mainly granular quartz (Pl. X., fig. 28). The quartz grains have been crushed and strained, and in some of them a band of quartz mosaic has been developed along

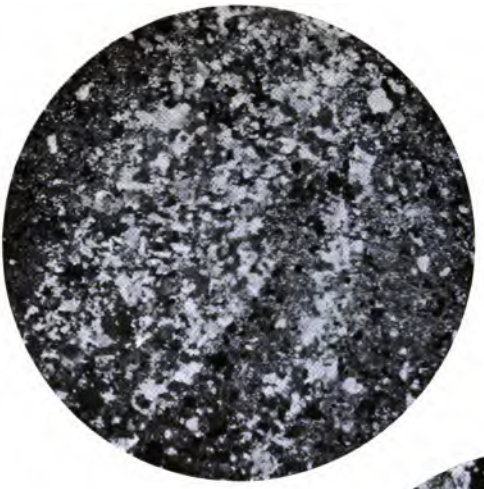


FIG. 28.— QUARTZITE. — With bands of quartz mosaic and scattered pyrites. Mount Lyell contact with "horse" of schist.

+ Nicols. × 14 dia. [No. 199].

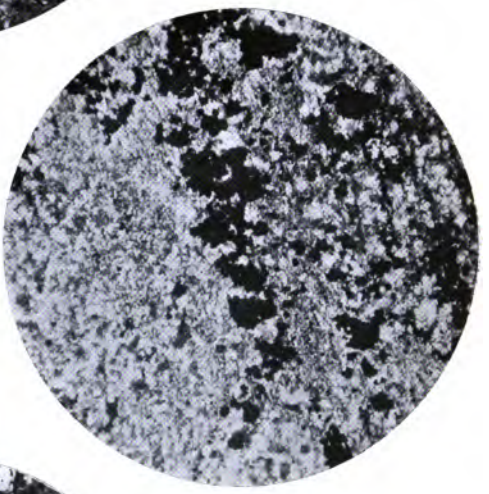


FIG. 29.—CHERTY QUARTZITE.—With bands of pyrites; all the quartz has been re-crystallized. North drive of the No. 6 level, Mount Lyell Mine.

+ Nicols. × 20 dia. [No. 213].

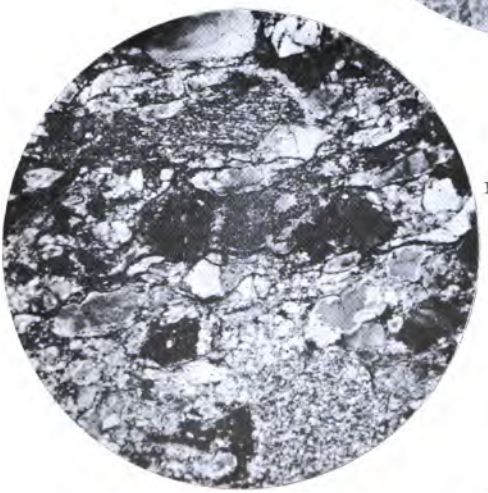


FIG. 30.—RED QUARTZITE.— From Gormanston Gap, with included fragments of the Lyell schists.

+ Nicols. × 22 dia. [No. 131].

PHOTO—H. J. GRAYSON.

ROCKS OF THE

CONGLOMERATE SERIES.

the crushed line. The rock contains abundant well-formed pyrites crystals, and is traversed by seams of secondary quartz mosaic. It has been more altered and more mineralized than the two rocks further from the contact.

Some of the fine quartzites have been previously called chert. This rock may be represented by a sample (No. 213) from the Mount Lyell mine, from the north drive of the No. 6 level, from the end of No. 2 bore. The rock is a compact and cherty quartzite; but as the fracture is rough and granular, and not conchoidal, it is not true chert. Examined microscopically, it shows eyes of quartz, surrounded by a dark mineral, and the aspect is crushed and foliated. Examined microscopically (Pl. X., fig. 29), the dark band seems to be all pyrites, and some of the pyrites has inclusions of an opaque bluish-white mineral, which formed the centre around which the pyrites has grown. The whole of this rock has practically been altered, the original quartz having been almost entirely re-crystallized.

A second sample (No. 214) of this rock is from the No. 2 bore between the depth of 150 feet and 155 feet. The rock, examined by the naked eye, is seen to be composed of intergrowths of pyrites and cherty quartzites. The pyrites nodules are flanked by quartz, which, examined microscopically under crossed nicols, is shown to consist of large secondary re-growths, radial from the pyrites; these secondary quartz crystals are intergrown with some pyrites crystals, so that the change in the nature of the quartz was produced at the time of the development of the pyrites.

Some quartzites taken further from the ore deposits are less altered. Thus No. 131 is a specimen of red quartzite from close to the Gormanston Gap, and is composed mainly of simple quartz grains, which are surrounded by a red ferrite paste in the redder parts of the slide (Pl. X., fig. 30). There are abundant inclusions of sericite, no doubt derived from the schists, and the slide contains fragments of the typical Mount Lyell schist, of the variety with large quartz grains and a marked flow-like foliation structure. The rock in this part of

the field has an abundance of these schist inclusions, which alone is sufficient to prove that the quartzites are later in age than the schists.

The rock at Karlson's face (No. 65), on the North Lyell Spur, is a fine-grained conglomerate with quartz grains and rounded grains of schist. There are some included felspars, of which the angles are but slightly worn, and there is an abundant development of chlorite between the coarser constituents of the rock.

Chapter X.—The Fenestella Shales.

The last of the stratified beds in the Palæozoic group of Mount Lyell is a series of black shales, containing many bryozoa, and occurring along the Linda Valley. They are exposed in the bed of the creek on the flat beside the Linda township, where they strike from 100° to 110° and dip 70° north. They outcrop from below the Gormanston moraine, and can be found at intervals along the edge on the southern side of the Linda Valley. In some cases the black clays appear to have been disturbed and re-deposited by glacial action. They contain better fossils than any of the other beds in the Mount Lyell area, and a search under suitable conditions of weather should yield sufficient material for definite determination of their age. Lithologically, they strikingly resemble the lower Carboniferous shales. My specimens were imperfect, but the bryozoa appear to belong to the Tasmanian Permo-carboniferous, rather than to the Silurian or Devonian. I could not find any exposure which clearly showed the relations of the Fenestella shales to the Devonian conglomerates; but the general evidence suggests that some marine carboniferous shales had been faulted down along the line of the Linda Valley, and thus preserved. A careful search for fossils in this bed, when the creek is low, should yield sufficient material for definite decision on this point. Some brachiopods from this bed have been sent to Hobart and identified as of Carboniferous age. Otherwise the position of these patches of shale suggested the possibility of their being part of an older bed than the conglomerates, outcropping beneath them.

Chapter XI.—The Post-Palæozoic Rocks.

After the close of the Palæozoic period there is a great gap in the geological record at Mount Lyell. There are no traces of sedimentary Mesozoic deposits; but the peak of Mount Sedgwick is formed of a block of Mesozoic diabase. This rock is an outlier from the diabase of the Eldon Range and from the wide sheet which, according to Johnston's sketch map, forms the great central plateau of Tasmania. These diabases, according to T. R. Stephens,* are of laccolitic origin, a view with which the character of the diabase on Mount Sedgwick is not inconsistent.

After this date the only deposits of any special interest in the Mount Lyell area are the glacial beds. A series of boulder clays occurs round the northern, eastern, and southern flanks of Mount Lyell. Gormanston stands upon a high moraine, which once dammed up the Linda Valley, forming a glacier lake between Gormanston and the ridge to the west. A glacier certainly rose high up the schist ridge at the head of the Linda Valley, and probably part of the ice crossed the divide and reached Queenstown; for immediately opposite the smelters is a bank of boulder clay containing diabase boulders, the most typical of the erratics in this district. The Gormanston Gap, through which the road from Mount Lyell passes to Queenstown, was probably worn by the outlet from the glacial lake that once existed above the Gormanston moraine. These glacial deposits are of comparatively recent date, and may be safely regarded as Pleistocene.†

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* Stephens, T., "Notes on the Diabase of Tasmania and its Relations to the Sedimentary Rocks with which it is Associated," Rep. Austral. Ass. Adv. Sci., vol. ix., 1902 1903, pp. 251–263.

† Gregory, J. W., "Contribution to the Glacial Geology of Tasmania," Quart. Journ. Geol. Soc., vol. lx., 1904, pp. 37–53.

Chapter XII.—The Faults of the Mount Lyell Field.

The most important, and in some respects the most interesting, feature in the structure of the Mount Lyell field is its great faults, The rocks of the field have been but slightly folded. There are a few folds; thus both an anticlinal and a synclinal occur in the conglomerates in the neighbourhood of the Mount Lyell Blocks (Fig. 7), while an inverted synclinal extends nearly all the length of the field in immediate proximity to the chief fault (see Pl. XVII., section E). The folds, however, are of subordinate interest, in comparison with complex series of faults (*e.g.*, Fig. 8). The most important of these faults runs north

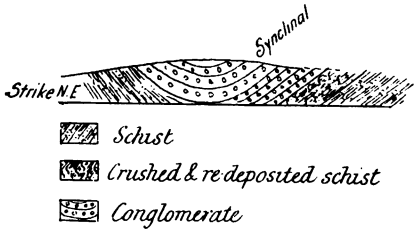

Fig. 7.

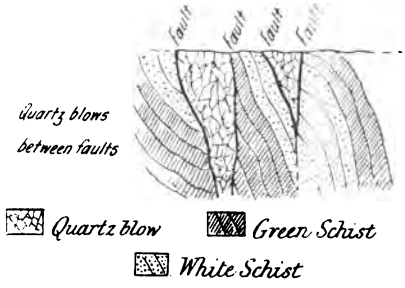

Fig. 8.

and south across the field, and may be called the Great Lyell Fault. It is an overthrust fault which has caused the schists to overlie the conglomerates. This fault disappears to the north beneath the Sedgwick Valley, but it can be traced still further north across the western end of the ridge of Mount Sedgwick. Its course southward from the Sedgwick Gap can be traced through the leases 130/93M, 602/93M, and 604/93M, shown on the lease plan of the field (Pl. XVI.)

The Great Lyell Fault is broken by a cross fault along the southern face of the western buttress of Mount Lyell. This buttress ends to the west, along the plane of the Great Lyell Fault. The cross fault has thrown the conglomerates down into the Queen Valley far below their normal level. The West Lyell buttress stands out as a conspicuous bluff, which forces the track from North Lyell to the Lyell Comstock mine to cross the Mount Lyell ridge, almost on a level with the summit; while the Great Mount Lyell Fault has been thrown 30 chains to the east by the "buttress cross fault" across the lease held by the Crown Lyell Company. The Great Fault then resumes its southward course, and the junction of the schists and conglomerates occurs at about the level of 2,100 feet. A cutting in the Crown Lyell lease, at the level of 2,150 feet, gives a clear exposure of the faulted junction between the conglomerates and the schists. The conglomerates at this section are of white quartzite, containing a good deal of pyrites, and are seamed in all directions by quartz veins. The fault face of the conglomerates is marked by broad basin-shaped depressions, and low, blunt, hump-like elevations; the projections are 18 inches in diameter, and about 6 inches in thickness (Fig. 9). The surface has been smoothed, but not

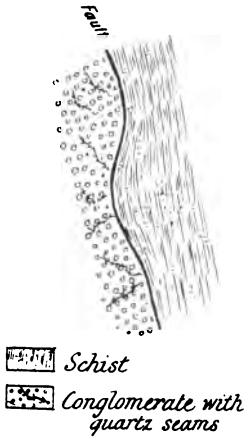

FIG. 9.

slickensided, the schists having been too soft to scratch the quartzites. The schists at the contact have been crushed and forced into the hollows between the projections of the conglomerates; but a foot or two away from the contact they dip from 65° to 70° to the west. The fault is a reversed fault, dipping to the west, and the schists overlie the conglomerates.

The Great Lyell Fault can be traced further southward, past the North Lyell and the Lyell Tharsis mines and over the head of the North Lyell Spur. The best exposure, at the North Lyell "open cut," shows the schists striking almost at right angles to a wall of conglomerate; this wall has been cleared, leaving a somewhat smooth face, which projects in a series of blunt elevations and shallow basin-shaped depressions. This face runs north 20° east, and is clearly a fault face, the schists opposite it striking almost at right angles to it.

The junction of the conglomerate and schists on the North Lyell Spur occurs just below a hut on the crest and above a conspicuous shoulder of that ridge. The conglomerate there dips 63° to the east, striking 10° west of north; while the schist dips 85° to the west, and has a strike of 35° to the west of north. The fault which separates them, however, dips to the west, so that the schists appear to overlie the conglomerates.

The Pioneer Spur shows a good exposure of the Great Fault, the schists again overlying the conglomerates at the eastern end of the spur. South of the Pioneer Spur the Great Lyell Fault is thrown to the west, and it passes along the Razorback, which consists of a ridge of red quartzites, dropped by two faults between the schists.

South of the Razorback is a series of sections along the Haulage, which give the best apparent evidence in favour of the interstratification of the conglomerates and schists. The section near the western end of the Haulage shows the two rocks apparently in definite interstratification; but when the section is examined carefully it is found that the two series of rocks are dove-tailed by faults. No less than four bands of the conglomerates have been forced in between bands of schists. The best section is on the

northern side of the cutting, at the eastern end of the Haulage. The red quartzites occur at the lowest part of the section; above them is a band of crushed purple schist, traversed by a small thrust plane, which has a throw of a few inches, and ends off against an almost vertical fault (Fig. 10). The coarse schists are traversed by

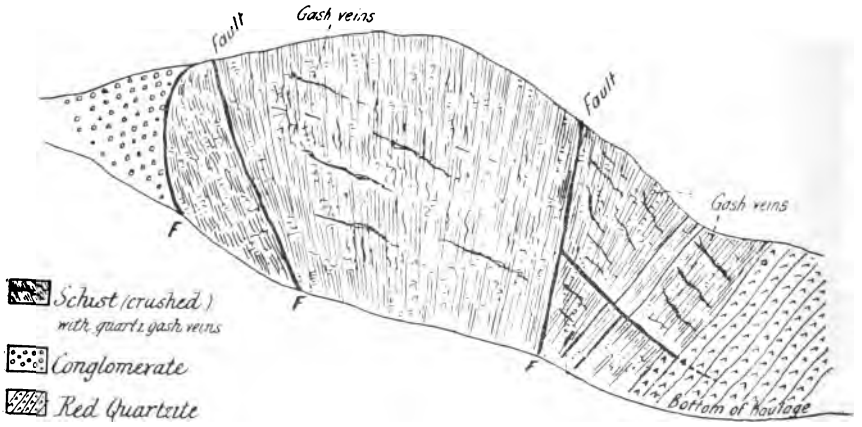

FIG. 10.

horizontal gash veins, filled with quartz. At the upper end the schists are broken across by two faults; one is a fault with a dip of about 70° to the east; above this fault is a band of crushed, brecciated schist, bounded to the west by a curved fault. Then follow four alternations of conglomerate and schist, which can be most easily explained as due to four thrust planes, below each of which the rocks have been thrust to the east.

There is a similar alternation of schist and conglomerate in a tunnel driven from the No. 5 level of the Mount Lyell Mine. The relations of the rocks there are also due to the dove-tailing of the rocks together along the great overthrust fault. The sections here were not easily accessible at the time of my visit, but the microscopic study of specimens collected for me by Mr. Batchelor's assistant, Mr. Murray, shows that this interpretation is correct. Thus specimens (No. 22) of the interstratified schist and conglomerate from the Mount Lyell Mine, No. 5 level, No. 2

west drive, include some fine-grained red quartzite, interstratified with highly-cleaved, fissile schists. The mode of association at first suggested the regular interbedding of the two rocks, but close study of the specimens shows that the apparent interstratification is the result of fault movements. Some of the specimens of the conglomerate are faced with crushed schist; in one specimen there is a pebble of schist in the sandstone; and a third specimen, from which the section has been cut (Pl. XI., fig. 31), is a greenish breccia, composed of fragments of red quartzite, broken quartz, and crushed schist. The quartz grains often show complex strain effects, and some of the larger crystals have very sharp angles. Some of the quartz inclusions show an interesting mylonitic structure, a movement having been set up in the rock by pressure, which has caused the flow of the finer material around the larger grains. The finer material has an irregular foliation, and the quartz grains are seen, under polarized light, to be altered by the development of quartz mosaic along their borders.

The microscopic structure of these rocks shows that the apparent interstratification of schist and conglomerate beside the No. 5 tunnel of the Mount Lyell mine is due to earth movements.

The Great Fault continues southward along the eastern wall of the Mount Lyell mine, where a thin layer of schist separates the conglomerates from the great pyrites mass. At the south of the mine a cross fault with a throw of about five chains to the west, has again shifted the course of the Great Lyell Fault, which must continue southward past the South Lyell mine. Thence its course is hidden for a while by the glacial deposits of Gormanston; but it can be recognized along the western foot of Mount Owen, and in the waterfall on Conglomerate Creek (Fig. 4, p. 66). In that district, however, the fault is no longer reversed, but is a normal fault. The Great Fault crosses the southern spur of Mount Owen, where it has tilted some of the lowest members of the conglomerate series to a high angle, and forced them against some bands of conglomerate, which are dipping gently to the south. South of this uplifted band of conglomerate the schists extend across the main divide.

G

The continuity of the Great Fault of Mount Lyell is broken by a series of transverse faults and thrust planes, which have had a marked influence on the geography of the field. The long transverse fault along the northern face of Mount Lyell has determined the position of the Sedgwick Valley. A parallel fault to the south has formed the western buttress of Mount Lyell, where the conglomerates extend further west on the northern than on the southern side of the cross fault. And, at the eastern end of Mount Lyell, the eastward extension of the conglomerates northward of the confluence of the Linda and King Rivers is probably due to the action of the same fault. A complex series of cross faults occurs near the North Lyell Mine (Fig. 11), but I had no

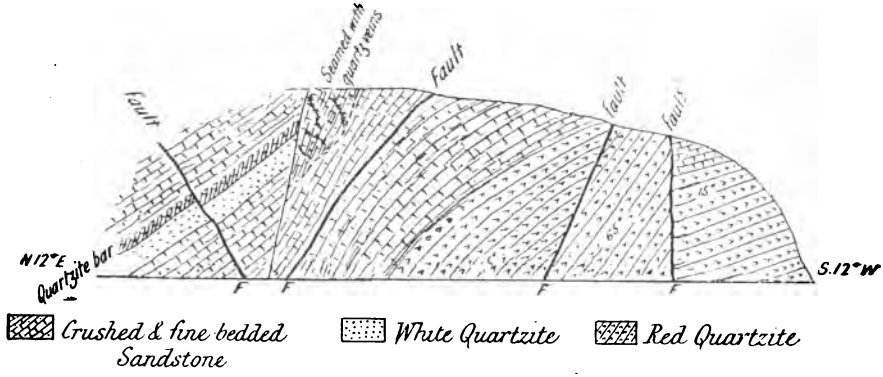

FIG. 11.

opportunity to examine that mine, except for a couple of brief visits to the open cut. Between the North Lyell Mine and the southern end of Mount Owen there are 12 well-marked cross faults.

A tunnel at the South Tharsis mine has recently supplied a clear illustration of the faulted contact of the schists and conglomerate. The South Tharsis mine was begun as an open cut on a big body of siliceous ore. A tunnel at the level of 1,420 feet has recently

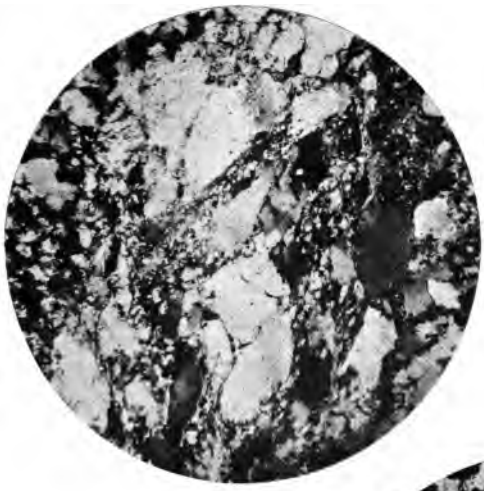

FIG. 31.—MYLONITIC CONGLOMERATE.—With inclusions of schist. From the alternating bands of schist and conglomerate, No. 2 west drive, No. 5 level, Mount Lyell Mine.

+ Nicols. × 37 dia. [No 22].

FIG. 32.—BANDED ORE OF PYRITES, fahlore encrusting pyrites, and quartz. Open cut, No. 2 bench. Mount Lyell Mine.

+ Nicols. + 14 dia. [No. 230].

FIG. 33.—ENRICHED ORE OF PYRITES, with bornite, quartz and barite. No. 3 rise, No. 4 tunnel, south drive, Mount Lyell Mine.

+ Nicols. × 29 dia. [No. 229].

PHOTO—H. J. GRAYSON.

CONGLOMERATE & ORES
OF
MOUNT LYELL MINE.

been driven eastward from below the open cut; it passed through schist until it was brought up abruptly against an almost vertical fault face of the conglomerates. A drive was then driven along this fault, going north 5° west. (Fig. 12.) The schists along

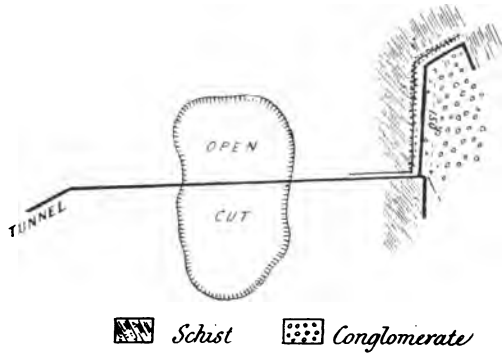

FIG. 12.

the fault line were crushed and brecciated and charged with copper and sulphide ores. After driving for 150 feet to the north 5° west, the contact between the conglomerates and schists suddenly diverged to the north-east, along the line of a second fault. The schists here had a north-westerly strike. After the fault plane had run for some distance to the north-east, the conglomerates were left behind, and the fault continued northward through the schists. The conglomerates were thus only a block, bounded to the west and east by north and south faults, which had let this mass of conglomerate into the schists. The main western fault face had a very high dip to the west; but a bore from the level of 1,482 feet passed through the continuation of this conglomerate to the level of 932 feet. Hence the vertical fault is apparently cut across below by a thrust plane, which slopes down to the west at an angle of $\frac{1}{2}$ in 1, parallel to the continuation of the ore bed.

A striking illustration of the powerful faulting which the rocks of the Mount Lyell field have undergone is afforded by the pebbles

in the conglomerates. Many of these have been broken in half, the two halves displaced, and then re-cemented, one part projecting. Two such cases are shown in Fig. 13. Such pebbles occur in the

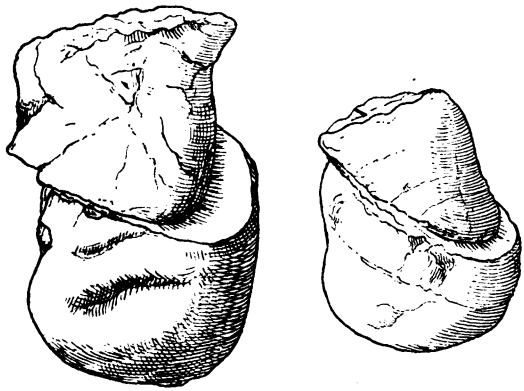

FIG. 13.

mullock heap of the Mount Lyell Blocks mine; and they are most abundant in the conglomerates beside the fault valleys of the western slopes of Mount Owen.

Chapter XIII.—The Ore Deposits of Mount Lyell.

(A.)—THE FAHLBANDS.

The ore deposits of Mount Lyell consist of two types—(1) mineralized bands of schist, and (2) great lens-shaped masses of very pure sulphide ores. Bands of pyritiferous quartzite also occur in the conglomerate series, and may be regarded as of similar origin to the bands of mineralized schist; but only the latter contain sufficient ore to be of any economic importance.

The minerals which occur in the bands of mineralized schist are chiefly iron pyrites and fahlore, associated with copper pyrites and bornite. These minerals are in places loosely disseminated through the ordinary schist; elsewhere they occur in the siliceous schists, forming acid copper ores, and some bands of low grade material that has hitherto only proved of value as a flux in smelting the pure pyritic ores of the great ore bodies.

The mineralized bands are widely spread through the schists of the Mount Lyell field. Their interest was recognized by Haber, who identified them as fahlbands, the most appropriate name for them. That the term is well applied to them may be seen by reference to any recent definition. Thus Professor J. F. Kemp, of Columbia University, defines fahlbands as "belts of schists which are impregnated with sulphides, but not in sufficient amount in the locality where the name was first applied (Kongsberg, Norway) to be available for ores."* The fahlbands of Mount Lyell are widely distributed through the schists, but occur especially along the course of the chief transverse faults. As examples may be quoted some bands of mineralized schist along the North Lyell road to the west of the North Lyell Gap; there is a good representative in the ground held by the Copper Mines of Mount Lyell West, and

* Kemp, J. F., "The Ore Deposits of the United States and Canada," 3rd edition, 1900, p. 73.

near by, on the boundary between the lease of the same company and the West Lyell Extended, the strike of the rocks is extremely confused, probably owing to movements along the continuation of the fault, which runs along the southern scarp of the North Lyell Spur. Another illustration of the fahlbands occurs south of the haulage, on the ridge overhanging the Gormanston road, where some works have been opened in mineralized schists, in the western end of the lease 4691/93M. The strike of the rocks immediately to the north of this band is extremely confused, probably owing to the westward continuation of the fault, which runs along the northern face of Mount Owen and on the southern bank of the Linda Valley.

The lodes here (lease 4,691/93M) were formerly called "The Block," or "Mrs. Fraser's Lode," and are now known as the "Lower" and "Upper Reserve Tunnels." The foliation of the schists strikes 130°. The ore is in bunches, which vary in thickness from four feet down to one foot. The bunches are about six feet in length, and they are separated from one another by several feet of barren country, composed of crushed and brecciated schist. The ore bunches were traced, during some prospecting work, 80 feet downward and 30 feet upward; they appear to have been a series of chimney-like shoots along a fault plane running parallel to the country rock. At the upper tunnel the rocks are the ordinary Lyell schist, separated by bands of quartzitic schist, with a strike of 125°. At the mouth of the tunnel is a mass of iron pyrites, separated from the schist by a fault which dips to the west.

The ore from these workings consists mainly of pyrites and fahlore; and the average of all the daily assays taken in the rise along the ore shoot was—

Copper	6·96 per cent.
Silver	0·36 oz. per ton.
Gold	0·008 oz. per ton.

In the ore of further workings the copper averaged 6·02 per cent. and 7·34 per cent. The ore is, therefore, for this district, high grade, but its small amount and erratic distribution deprive it of any economic value.

In the next lease to the south, on the hill slope above the Gormanston Road (4,692/93M) is a seam of barite in quartzose schist, the foliation of which trends to 120°, and dips to the north-west. The schists are traversed by thin lines of pyrites, resembling the pyritic "Indicators" of Ballarat. In the same lease there is a large deposit of mineralized schist well exposed in a tunnel, going at 55° into the hill at right angles to the foliation of the schist. The schists here are very siliceous and contain abundant seams of quartz and lines of pyrites. At this point there were no bunches of ore or shoots as at the Reserve Tunnel; but the schists are traversed by many seams and bands of pyrites. The tunnel was driven 100 feet in length, and according to Mr. Aaron White, the foreman in charge of the work, it did not pass half way through the pyritized rock, which can be traced on the surface for a greater thickness.

The tunnel of the Mount Lyell Reserve Company on the left bank of Conglomerate Creek, close to the stream, was begun at the outcrop of another fahlband. The tunnel was driven for more than 60 feet, through dark green schists with a strike of 120°. A thin band of ore was passed through at the mouth of the tunnel; but no more ore was found within it; and no effort was made to follow the deposit along the strike, probably from absence of any sign of its extension in that direction. The ore is said to have yielded 4 per cent. of copper.

The fahlbands, which are mere pyritized bands of schist, have so far proved of more scientific and historic interest than of economic importance. Their discovery in so many localities encouraged the hope that many great pyrites bodies existed in the district. They thus led to the belief that the copper ores are deposited in a series of lodes running continuously north and south across the field. Hitherto the attempts to work these pyritized seams have been unprofitable; but there is a more important series of fahlbands, which have been successfully worked by the Mount Lyell Mining and Railway Company as metal-bearing fluxes. The basic pyritic ores of the Mount Lyell mine require a siliceous flux, and the acid ores of the larger fahlbands serve this purpose and contribute their own copper contents at the same time.

(*a.*)—*The South Tharsis Mine.*

The South Tharsis mine is situated three-quarters of a mile to the north of the Mount Lyell mine, and one-quarter of a mile to the south-west of the North Lyell. It contains a band of pyritized schist, which was worked by an open cut, developed on three benches; and its subterranean extension has been explored by a diamond drill bore put down to the west of the outcrop. The mine was worked by a company in 1899, which began the open cut and erected concentrating works on the slope below the mine, on one of the tributaries of Glover Creek. The process, however, was not a success, for the brittle copper pyrites was crushed to a slime, and much of it was lost, while too much of the iron pyrites remained in the concentrates. The property of the company was acquired in 1900 by the Mount Lyell Mining and Railway Company, which could profitably smelt the material as a siliceous flux in conjunction with its own basic ores.

The metalliferous material is developed as a fahlband, and is well shown in the open cut. Its well-defined western wall trends north 25° west, and is parallel to the strike of the adjacent schists. The fahlband is continued below by a band which dips to the west at an angle of 1 in 2, and was pierced by a bore put down from a point in the hill slope at the level of 1,482 feet above the sea. The geological relations of this body have been proved by a tunnel below the open cut, which has been driven eastward till it ended against the vertical fault face of the conglomerate, which is almost vertical, but has a slight dip to the west. The faulting and relations of the conglomerates and schists in this mine have been already described on p. 82.

An underground extension of the Royal Tharsis ore body in the lease of the South Tharsis mine has been proved by a series of drives. The south-eastern "hanging wall drive" followed the hanging wall of the fahlband for 146 feet, and proved the occurrence of the metal-bearing flux all along it; and the No. 4 cross-cut from this drive passed through 65 feet of the metal-bearing schist, which is of a satisfactory grade for that thickness.

The south-eastern hanging wall drive, No. 2, from the Royal Tharsis mine, explored a separate belt of mineralized schist, which is to the east of the main belt. This drive crosses the northern boundary of the South Tharsis lease, and crosses the strike of the metal-bearing schist obliquely for 197 feet.

The South Tharsis, to the end of September, 1902, has yielded 49,287 tons, with an average assay value of copper 1·64 per cent., silver 0·22 oz., and gold 0·022 oz. The variations in the yield may be illustrated by the figures for the material worked for the half-years ending 31st March, 1901, 31st March, 1902, and 30th September, 1902, in which the amounts yielded were respectively 8,353 tons,* 12,779 tons,† and 17,666 tons,‡ giving an assay value of—

Copper ..	1·54 ..	1·67 ..	1·68 per cent.
Silver ..	·19 ..	·24 ..	·24 oz.
Gold ..	·019 ..	·019 ..	·026 oz.

The average composition of the South Tharsis flux‖ includes—

Silica	62·67 per cent.
Iron	8·05 per cent.
Alumina	12·17 per cent.

(*b.*)—*The Royal Tharsis Mine.*

The lease of the Royal Tharsis mine is immediately to the north of that of the South Tharsis, and contains an extension of the same belt of mineralized schist. As, however, the material has to be obtained by underground workings, it is more expensive to work than that of the South Tharsis mine. Therefore, though its grade is somewhat higher, it has been less worked. The property was acquired by the Mount Lyell Mining and Railway Company early in 1901, and is developed by three underground levels.

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* The Mount Lyell Mining and Railway Company Limited. Reports and Statements of Account for half-year ending 31st March, 1901, Melbourne, p. 21.

† *Ibid.*, for the half-year ending 31st March, 1902, p. 24.

‡ *Ibid.*, for the half-year ending 30th September, 1902, p. 25.

‖ Rep. Sec. Mines, Tasmania, 1901-2 (1902), p. cxl.

The Royal Tharsis mine yields a siliceous flux of schist containing pyrite and chalcopyrite. The mine yielded up to September, 1902, a total of 2,274 tons of ore, of an assay value of copper 2·11 per cent., silver ·24 oz., and gold ·023 oz. For the half-year before the 31st March, 1902, it yielded 1,403 tons with an assay value of copper 2·04 per cent., silver ·22 oz., and gold ·021 oz. For the following half-year it yielded 871 tons with an assay value of copper 2·21 per cent., silver ·27 oz., and gold ·027. The average composition of the metal-bearing flux of the Royal Tharsis* includes—

Silica	61·17 per cent.
Iron	9·94 per cent.
Alumina	10·44 per cent.

(c.)—*The Lyell Tharsis Mine*

The Lyell Tharsis mine lies in the lease adjacent to the North Lyell mine. The ore body extends into the North Lyell area, and is now being worked by the amalgamated company. The mine contains a body of siliceous ore, which is lenticular in shape, and was about 20 feet wide in the best part. The mine was worked by an open cut, which shows a clear section of the adjacent rocks.

(B.)—THE ORE MASSES.

(d.)—*The Mount Lyell Mine.*

The great masses of sulphide ores are the source of the wealth of the Mount Lyell field. There are two main ore bodies. The largest is that of the Mount Lyell Mining and Railway Company, known as the "Big Mine," or "Parent Mine," and as the "Iron Blow." The mine is situated at the height of 1,415 feet above sea level, on the eastern flank of the ridge of schists which con-

* Rep Sec. Mines, Tasmania, 1901-2 (1902), p. cxl.

nects the western end of Mount Lyell to Mount Owen, across the head of the Linda Valley. It is situated to the south of the eastern end of the haulage, and to the north of the town of Gormanston. When first discovered most of the surface of the ore body was covered by a deposit of gravel and soil from 12 to 20 feet thick, and supporting a growth of button-grass. In places, especially toward the northern end, the soil was very shallow, and the watercourses had cut down to the ore body, exposing the fresh, unoxidized pyrites. At the southern end of the ore body, between it and the country rocks, was a thick ironstone gossan and the hematite of the iron blow. The gossan was composed mainly of silica, barite, and iron oxide, which contained also 15 ozs. of silver and 15 dwts. of gold. The pyrites had been decomposed, and all the copper and most of the iron removed by leaching. This deposit was long since removed, and all sign of the surface outcrop is now destroyed. The ore body trends about N.W. by W., and its length on the surface was 800 feet and its width 200 feet. It is worked by an open cut, by a series of nine terraces or benches. The present floor of the excavation, No. 4 bench, is 272 feet below the original top of the deposit. The ore has now all been removed above the four uppermost benches. The excavation at the end of 1901 was oval-shaped, 800 feet long, 630 feet wide, and 272 feet deep. Beneath the open cut is a series of underground works, including levels Nos. 5–8, by which some masses of rich ore have been mined, and the size of the ore mass determined at the successive levels; the further extension has been tested by diamond drill boring.

The chief facts as to the size and shape of the Mount Lyell ore mass have been definitely determined. It is irregularly boat-shaped in form, consisting of an elliptical mass, which tapers gradually downward, and is then cut off below with a rounded base. Horizontal sections across the ore mass (Pl. XVIII.) are irregularly elliptical, and the major axis of this ellipse at the various levels is not always in the same direction. The ore body, in fact, has undergone an apparent torsion, which is shown by the table showing the trend of the major axis at the successive levels:—

No.	Length.	Width.	Trend of major axis.
3	..	..	N. 50 W.
4	660 feet	270 feet	N. 43 W.
5	510 feet	210 feet	N. 45 W.
6	510 feet	270 feet	N. 64 W.
8	280 feet	..	N. 88 W.

There is little doubt that the great pyritic mass of Mount Lyell is limited in depth. It has been cut off below by a great thrust plane, which brings the conglomerates under the ores and schists, 97 feet below the centre of the No. 8 level, which is 755 feet above sea level.

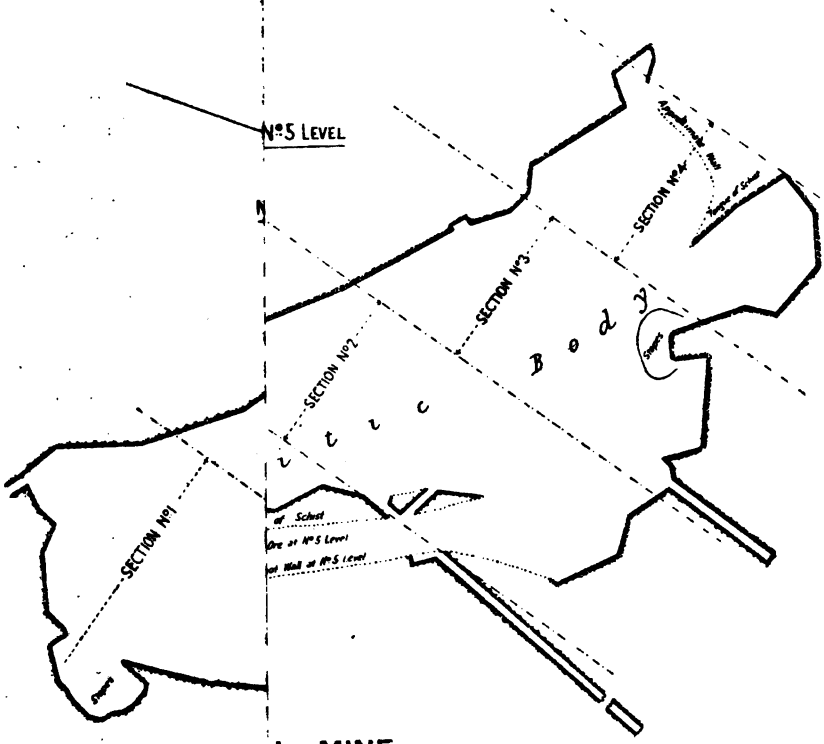
The ores in this ore body are of remarkable purity and uniformity. Peters remarked that in a width of 300 feet across the mass "in the entire distance there is not a piece of gangue rock as large as a walnut" (p. 10). The ores consist almost entirely of iron pyrites containing copper, gold, and silver. There is little galena and less sphalerite (zincblende). The only two important minerals forming gangue are quartz and barite.*

The most remarkable feature in the Mount Lyell pyrites is the comparative richness of the precious metals. The copper, gold, and silver are not uniformly distributed through the pyrites, being less abundant in the ore near the hanging wall, which is in places so poor that it only pays to work as fuel in the pyritic smelting of the richer ores. The ores near the footwall are much richer; thus Peters' assays of a series of samples taken by 2-feet drill holes along the footwall of the southern drive of the No. 3 tunnel varied from 11 per cent. to 30 per cent. of copper.

The average yield of the mine is about 1,000 tons a day. It was at first proposed to limit the open cut to the No. 4 level, above which it was calculated that 693,045 cubic yards or 2,339,000 tons of ore could be obtained by the removal of 1,500,000 cubic yards of the overhanging schists as overburden.

* Mr. Stichl tells me that some selenium and less tellurium are also present, but both in infinitesimal quantities. There is a fraction of one per cent. of arsenic and of antimony, and no nickel, cobalt, or bismuth.

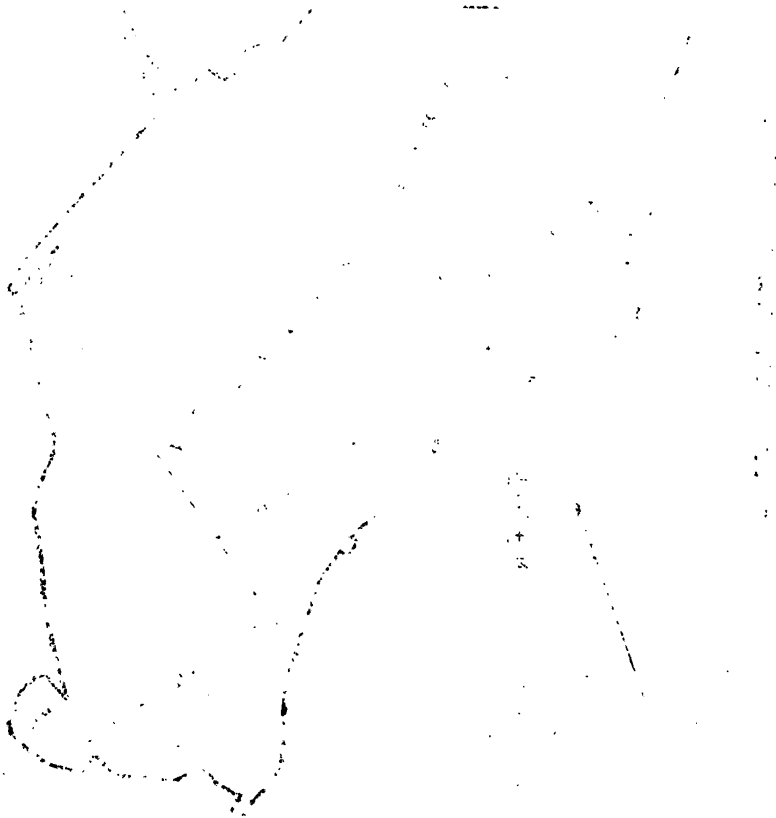
Plate XVIII.



L MINE,

Levels Nos. 4 & 5.

Arnall & Jackson Melb.



The average composition of the ore which pays to extract is—*

Iron	40·30
Silica	4·42
Barium sulphate	2·50
Copper	2·35
Alumina	2·04
Sulphur	46·50

Hence, in spite of the extreme care with which Dr. Peters took the samples, the general richness of the ore is below his estimate; for he excluded the poorer hanging wall portion of the deposit, and based his estimate on samples obtained from the footwall portion, which only was exposed by underground workings at the time of his visit. This richer ore has not proved to be representative of so large a part of the mine as the evidence then suggested.

The mine is by no means equally rich throughout, for the ore on the hanging wall side contains less copper and precious metals than on the eastern or footwall side, and the ore is also, as a rule, richer near the surface than at the deeper levels. Accordingly, for the purpose of estimating the available ore reserves, the mine is divided into five sections, which are numbered from 1–5, from the footwall to the hanging wall side. The three sections (1–3) on the south-eastern side of the mine contain the best ore; this has been described as the payable ore, but the limit between the grades of ore which pay to work and those which are useless, is of course variable; and now that the ore of the North Lyell mine and the Mount Lyell pyrites can be smelted together, some of the material in the fourth and fifth sections can be used.

Mr. Sticht estimated on the 31st March, 1901, that above the No. 4 level there was a total tonnage available of 978,337 tons, giving an average value of 2·35 per cent. copper, 2 ozs. of silver, and ·0725 oz. of gold to the ton. The two north-eastern sections (4 and 5) contained above the No. 4 level 648,328 tons of ore, of which the average assay value is ·64 per cent. of copper, 1·6 ozs. of silver, and ·06 oz. of gold. The prices of metals at that date were—

* Rep. Sec. Mines, Tasmania, 1901–2, p. cxxxvii. (1902).

copper £70 per ton, silver 2s. 3d. per oz., and gold £4 5s. per oz. Value of south-eastern ore was estimated at 43s. 7d. per ton, whereas ore of the second division was only worth 17s. 8d. per ton.*

Between levels Nos. 4 and 5 there was, according to Mr. Sticht's estimates of March, 1901, 1,723,218 tons of ore, and the average assay value of the whole of it was copper ·64 per cent., silver 2·15 ozs., and gold ·048 oz., which at the current prices of the metals was worth 17s. 10d. per ton. Within these levels there had originally been some masses of much richer ore, which had been entirely worked out before that date. Below levels Nos. 5 and 6 the ore available was at least 561,386 tons, the existence of which had been proved by the workings up to that date. Subsequent work has shown that this amount will be exceeded. In this zone of the mine the average contents of the ore are copper ·57 per cent., silver 1·74 ozs. per ton, and gold ·04 oz. per ton, and its value, according to prices in March, 1901, is 15s. 4d. per ton. Accordingly Mr. Sticht concluded that the original ore contents of the Mount Lyell ore mass had been 4,187,499 tons, of which there was still available on the 31st March, 1901, 3,349,883 tons, as well as the whole of the material below No. 5 level, the amount of which could not then be calculated.

The general form of the ore mass is shown by some cross sections published in the Mount Lyell Company's half-yearly report, No. 16. The first section (Fig. 14) passes through the southern part of the ore mass and reaches to the depth of the No. 7 level; in this section the open cut had been worked down to bench 3A, at the level of 1,214 feet. The section shows the gradual reduction below in the width of the ore mass, and the intrusion of two tongues of schist, which were cut through by No. 5 level. The second section (Fig. 15) is more central in position, so that the schist tongues were not represented, and the ore mass is wider below. A third section (Fig. 16) shows the beginning of the reduction of the width below. The fourth section, near the northern end

* The Mount Lyell Mining and Railway Company Limited. Reports and Statements of Account for the half-year ending 31st March, 1901, p. 26. Melbourne, 1901.

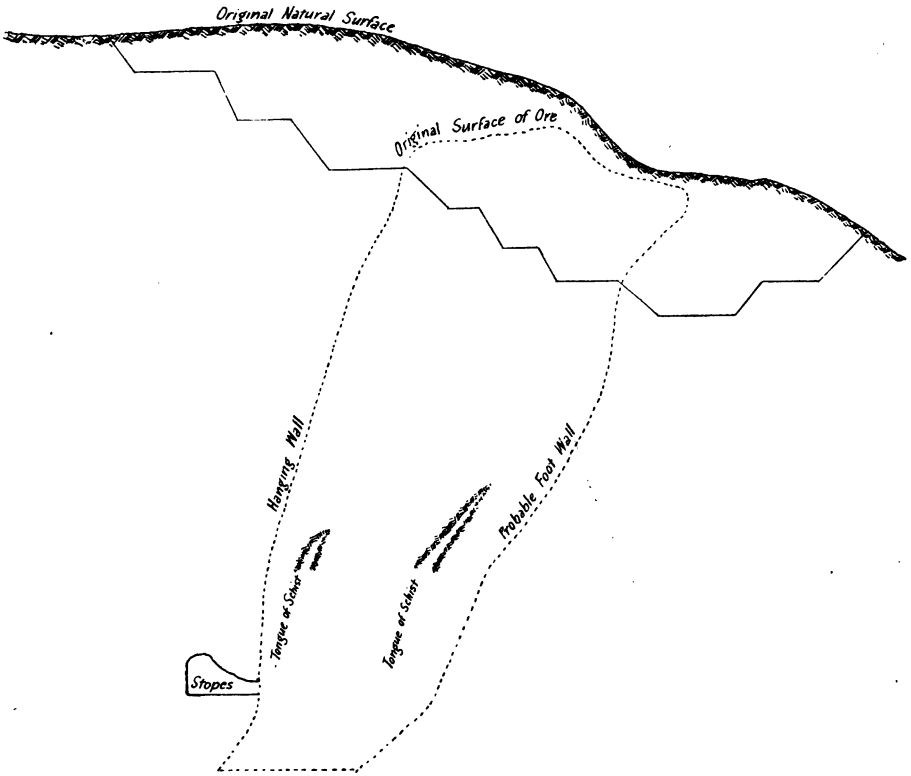


FIG. 14.

of the ore mass, is narrower and tapers more rapidly below, and an intrusion of a schist tongue indicates that the ore mass is reaching its north-western limit.

The remarkable purity of the Mount Lyell pyrites mass is one of its most striking features. It is generally uniform in grade, though the ore on the footwall side is much the richer; as a rule, the ore is completely free from any extraneous matter, but at the northern end there are some fin-like projections of schist into the pyrites.

Some masses of rich ores occur in the ore mass; most of them have already been removed by underground excavation, and they are therefore generally reported as the "stoped ores." These ores

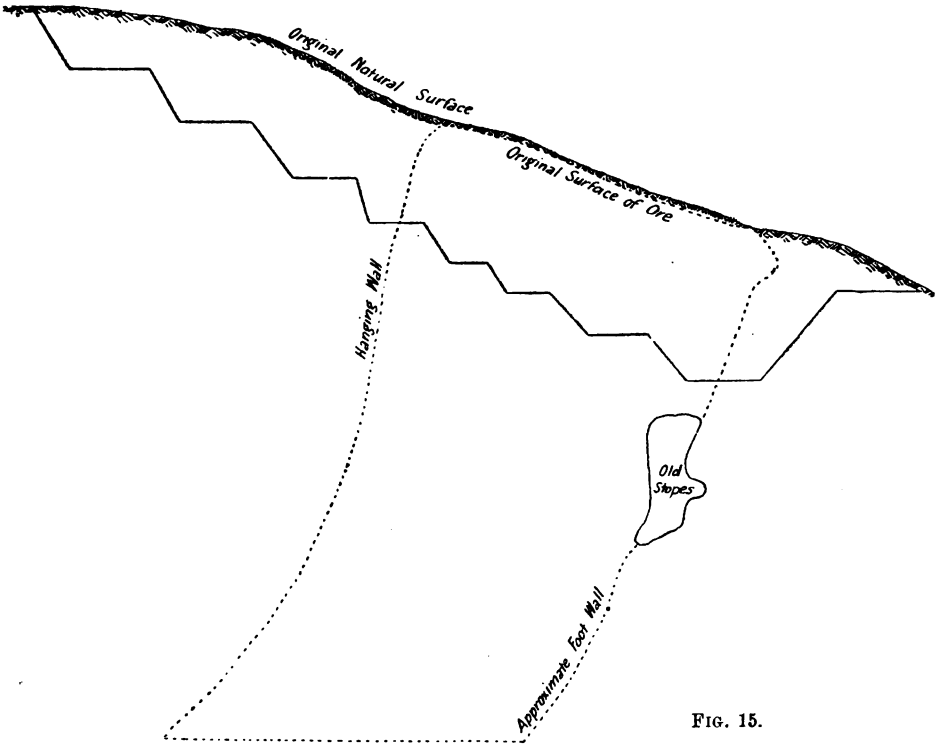


FIG. 15.

are siliceous, and the copper-bearing minerals they contain are bornite and chalcopyrite. The average analysis of these ores is as follows:—*

Iron	24·75 per cent.
Silica	30·69 per cent.
Barium sulphate	1·48 per cent.
Copper	5·33 per cent.
Alumina	6·30 per cent.
Sulphur	30·0 per cent.

The bornite enrichments form shoots, extending from the surface of the ore body to below No. 7 level; they occurred at both corners of the southern end of the ore body. The material was

* Report Sec. of Mines, Tasmania, 1901–1902, p. cxxxvii., Tasmania, 1902.

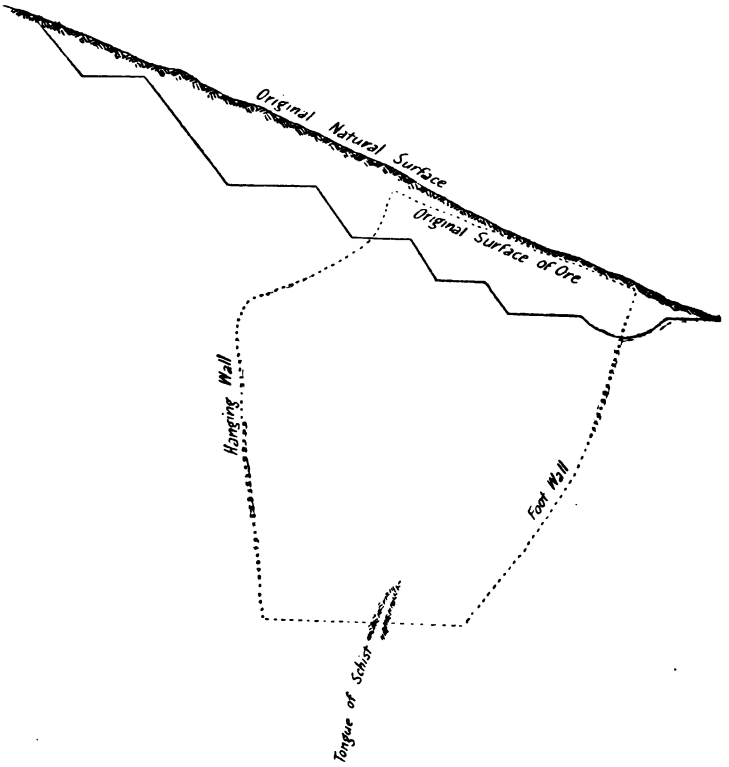


FIG. 16.

uniform in character, and consisted of a siliceous mixture of pyrites and bornite, while in the lower depths of the mine siliceous copper pyrites was also present.

In addition to the bornite shoots there are some much smaller enrichments of fahlore. One of the most interesting was discovered in the north hanging wall drive off the main tunnel at No. 5 level. The enriched ores were there 6 feet thick on the hanging wall side of the ore mass, and contained patches of solid fahlore in pyrites. The average assay value of this material was copper 3·65 per cent., silver 2·07 ozs., and gold ·02 oz.*

* Mount Lyell Mining and Railway Company Limited Reports and Statements of Account for the half-year ending 31st March, 1902, Melbourne, pp. 13, 14.

Similar, but apparently disconnected, shoots of the richer ore have been traced down to No. 8 level, and some of this ore was worked by a winze from the No. 7 level.*

More important shoots of the richer ores have been found on the footwall side of the mine. The largest, known as the Mount Lyell Bonanza, was discovered and worked out in 1894; it yielded 850 tons of ore, which was sent to London and sold for £105,000. This bonanza was found between the pyrites mass and the lower continuation of the hematite of the Iron Blow. It consisted of a vein of copper glance (redruthite, Cu_2S) and bornite, with fahlore and argentite (silver glance, Ag_2S). It was found in a drive from the No. 4 tunnel. The entire shipment averaged 1,011 ozs. of silver to the ton, and one specimen which was knocked off by Mr. Lewis, the Attorney-General of Tasmania, and was assayed by the Tasmanian Government Assayer, is quoted by Peters† as yielding 8,765 ozs. of silver and 45 ozs. of gold to the ton, and 19 per cent. of copper. Some specimens assayed nearly 50 per cent. silver. As the vein was followed downward it increased in thickness, being in places 2 feet in width. The discovery of this body of rich ore was of great importance in the history of the field, as it had a considerable influence in securing the capital necessary for the development of the mine.

On the footwall side, between the 5th and 8th levels, there have since been found several other fahlore enrichments; but none of them have been as important as that beneath the hematite blow.

A shoot of ore containing copper 4·55 per cent., silver 3·58 ozs., and gold ·119 oz., was found in the northern drive from the No. 5 level; but this shoot was not connected with the old bonanza of the higher levels. The stopes between the 6th and 7th levels yielded ore containing copper 10·94 per cent., silver 6·23 ozs., and gold ·022 oz.

* At No. 5 level the ore mass is constricted, both Nos. 4 and 6 levels having a larger superficial area.

† "Report on the Property of the Mount Lyell Mining and Railway Company Limited," p. 15, Melbourne, 1893.

The quantity of these richer underground ores is, however, comparatively small. For the half-year ending 31st March, 1902, they amounted to 6,479 tons, with an average assay value of copper 5·23 per cent., silver 3·45 ozs., and gold ·059 oz.;* and in the following half-year† 4,595 tons, giving an assay value of copper 4·93 per cent., silver 3·90 ozs., and gold ·064 oz.

These enrichments are of considerable interest, as they throw light on the genesis of the Lyell ores. The main bonanza occurs immediately below and opposite the great body of barytic hematite of the Iron Blow. This hematite was of very large extent, and has been generally recognized as derived from the pyrites.

It is, of course, obvious that the Iron Blow was not formed by the simple alteration of the pyrites by surface waters and air; for in that case the iron would have been present as a hydrous oxide of iron, such as limonite, instead of as hematite. Apparently limonite only occurred where the hematite had been acted upon by surface waters. It is accordingly most natural to regard the Iron Blow as some type of lode, formed under conditions which have led to the deposition of red hematite from iron solutions. The iron was probably leached from pyrites in the underlying rocks, and was precipitated along the fault lines, where the ascending waters, containing iron salts, met other solutions which had worked their way downward through the conglomerates. The position of the Iron Blow beside the pyritic mass is only natural, for the conditions which favoured the ascent of the solutions which deposited the pyrites, also enabled the ascent of the other. The anhydrous hematite was naturally also deposited where the conglomerates have been faulted down against the schists; for the surface waters could pass through the porous conglomerates and thus mix at some depth with the ferruginous waters and precipitate their contents.

* The Mount Lyell Mining and Railway Company Limited. Reports and Statements of Account for the half-year ending 31st March, 1902, Melbourne, No XVIII., p. 24.

† *Ibid.*, XIX., for the half-year ending 30th September, 1902, p. 25.

Mr. F. D. Power* has suggested that the Iron Blow is a segregation lode, thereby showing that he fully recognized that it was not formed by the mere decomposition of the pyrites. The striking difference between the ores of the Iron Blow and the pyritic masses is the poverty of the ironstone in copper and silver. These metals may have been once present in it; but they, being more easily removed as soluble sulphates, have been entirely leached out and carried down. The rich shoots of silver-copper ores found at the southern end of the pyritic mass of Mount Lyell probably derived their contents from the leaching of the Iron Blow. These bonanzas or enrichments are secondary enrichments, formed by water working its way downward through the ores and leaching out the more soluble salts; the metals in these salts were deposited again lower down, along the drainage lines in shoots, which thinned out below, as they got further from the source of supply.

The iron gossan of the Iron Blow was, therefore, probably formed from pyrites by the conversion of the iron sulphide into ferrous sulphate and of the enclosed copper and silver into cupric and silver sulphates. As a solution of ferrous sulphate is a solvent for gold, that metal also was removed at the same time. The solution then percolated into the schist of the hanging wall side, where further chemical changes took place. The ferrous sulphate was decomposed and the iron precipitated as ferric oxide (Fe_2O_3); the gold was immediately precipitated. The sulphate of barium, which had also been introduced at the same time, was precipitated along with the iron and gold, forming the barytic hematite of the Iron Blow. The copper and silver were perhaps precipitated in the hematite, and, being more soluble, have been subsequently removed by leaching processes, and then concentrated on the margin of the hematite. It appears, however, to be more probable that the copper-silver ores were deposited at the same time as the hematite, but at a slightly lower level, owing to their greater solubility. This conclusion is supported by the fact that the hematite shows little evidence of subsequent per-

* Power, F. D., "Notes on the Mount Lyell District, Tasmania," Proc. Roy. Soc., Tasmania, 1891, Hobart, 1892, pp. 27, 42, 43.

colation. Had water passed through it, the iron oxide would, in all probability, have been altered into limonite.

Peters estimated, after the most exhaustive and careful process of sampling, that the Mount Lyell ore would yield an assay value of copper 4½ per cent., silver 3 ozs., and gold 2½ dwts. He estimated the width as 300 feet; the length actually traced at that time was 950 feet. Limiting the payable ore to a width of 200 feet, thus excluding the low grade ores on the hanging wall, and taking the weight of the ores as 280 lbs. per cubic foot, he calculated that there would be 9,200,000 tons; deducting half that amount for contingencies, he estimated there were 4,600,000 tons of ore above the workings existing at that date, and above the level of the tunnel which it was then proposed to carry through the ridge to the smelting works at Queenstown. Actual work has, however, proved that the average of the ore used up to the end of September, 1902, was considerably poorer; 1,320,134 tons had then been smelted, which yielded an average assay value of copper 2·92 per cent., silver 2·74 ozs., and gold ·097 oz. (that is 1·94 dwts.).

(*e.*)—*The South Lyell Mine.*

The South Lyell mine is in a lease situated due south of the Mount Lyell mine, and in this lease a considerable body of low grade pyritic ore has been found. A shaft was sunk at a point in line with the Iron Blow of the Mount Lyell mine, in expectation of reaching the continuation of the Mount Lyell "lode." The mouth of the shaft is at the level of 1,368 feet above the sea; it reached pyrites at 844 feet above sea level, and continued through it to 720 feet above sea level, or 648 feet below the mouth of the shaft. This mass of pyrites, with an apparent thickness in the shaft of 124 feet, has been proved by subsequent work to be a large pyritic body, 140 feet long and 70 feet wide, running from north 50° west to south 50° degrees east. It must be cut off abruptly above, as, if it had continued upward at the same dip as in the shaft, it should have been passed through by a diamond drill bore made from the No. 5 to the No. 6 level of the Mount Lyell Company. The absence

of any extension from the South Lyell ore body in that bore shows that it ends abruptly above, just as the pyritic body of Mount Lyell ends abruptly below. The ore of the two mines is remarkably similar in character. Their distance from one another is approximately that of the throw of the great thrust plane which has brought the conglomerates between the schists in the Mount Lyell mine. Hence the evidence renders it probable that we have to seek for the subterranean source of the Mount Lyell ores through the South Lyell ore mass. The ores of the South Lyell mine on the footwall, just above the schist, are enriched with fahlore, due probably to the leaching from the ores along the hanging wall, and the deposition of the material on the lower side of the deposit. The South Lyell ore mass contains one large intrusion of schist. The average ore contains ·5 or ·6 per cent. of copper, and has been mined for use as fuel in the smelting of the acid ores from the North Lyell mine.

The mass of ore could be most economically worked by driving from the Mount Lyell mine. The ore is cut through by a fault, which left the pyrites polished like a mirror; a specimen of the slickensided pyrites from this fault is preserved in the Hobart Museum.

(*f.*)—*The North Lyell Mine.*

I was unfortunately unable on either of my visits to Mount Lyell to examine the underground workings of either the North Lyell or Lyell Blocks mines. An inspection, however, of the surface workings and subsequent information, kindly given to me by Mr. W. T. Batchelor, shows that both mines are associated with extensive faults.

The North Lyell mine is situated at the extreme head of the Linda Valley, beside some bold crags of conglomerate, which rise on the ridge which forms the divide between the Linda and Queen Valleys. The mine occurs close by the contact between the schists and conglomerates, the junction of which is complicated by an elaborate series of faults. The ore has been worked by a deep open cut, the bottom of which is 1,647 feet above sea level. The contact of the

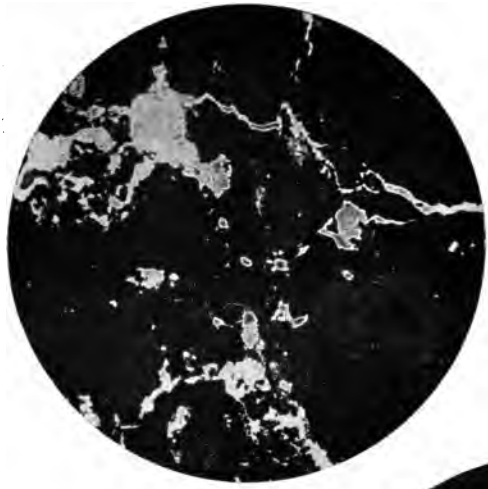


FIG. 34.—CRUSHED PYRITES.—With fahlore (dark lines) along cracks between the pyrites. The transparent material is mainly barite, with quartz veinlets. Mount Lyell Mine.

Combined polarized and condensed light. × 14 dia. [No. 231].

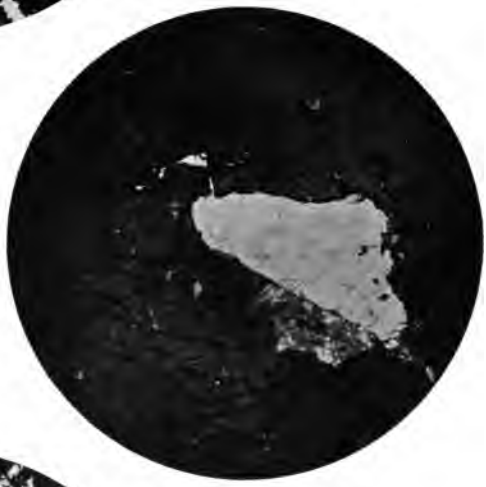


FIG. 35.—PYRITES.—With seams of galena (black), and a large quartz crystal. Mount Lyell Mine.

Combined polarized and reflected light. × 14 dia. [No. 228].

FIG. 36.—PYRITIC CHERT.—With bands of quartz mosaic. No. 6 level, Mount Lyell Mine.

Combined polarized and reflected light. × 14 dia. [No. 214]

PHOTO—H. J. GRAYSON.

schist and conglomerate is part of the Great Lyell Fault, which has a general trend from north-east to south-west; but opposite the main ore body a cross fault breaks across the Great Fault, throwing the southern part to the north-west. This face of the cross fault is well shown in the open cut, where the ore has been removed from the north of it, leaving exposed a bumpy, wavy surface of conglomerate.

* The ground included in the lease of the North Lyell Company is probably more faulted and disturbed than any other equal area in the Lyell field. The mine includes at least five distinct ore bodies, four of which are enclosed in schist and occur in the bays or angles between the Great Lyell Fault and the transverse faults. The so-called eastern ore body, on the other hand, occurs to the east of the Great Fault, and its ore is different in character and position from that in the ore bodies along the main fault. The eastern ore is a siliceous pyritic material carrying copper; it contains much organic matter, and has conglomerates on its northern side. The main ore body and those associated with it occur enclosed in schists. They are disconnected shoots of ore, formed of bornite, in siliceous schists. The largest body is known as the main ore body, and was once thought to have been part of the second largest body, which has been almost worked out by an open cut.

(C.)—THE MICROSCOPIC STRUCTURE OF MOUNT LYELL ORES.

The microscopic structure of the ores of Mount Lyell affords important evidence as to their genesis.

A specimen (No. 230) of banded ore from the open cut, at the No. 2 bench, consists of pyrites, steel grey fahlore, and quartz. Microscopic examination (Pl. XI., fig. 32) shows that the bands of fahlore are made up of granules composed of fahlore around pyrites; in part of the specimen, near the margin, some fahlore is developed in concentric growths.

The vein stuffs are partly quartz, but mainly barite, which is easily recognizable by its cleavage and straight extinction.

* For the information in this paragraph I am indebted to Mr. Sticht.

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The pyrites occurs in places in large, well-defined crystals; elsewhere it is crowded and granular. The fahlore sometimes occurs filling the interstices between the pyrites. One cavity in this specimen is filled half with quartz and half with fahlore, lines of of which project from the cavity into the surrounding pyrites. There can be no doubt in this case, that the quartz and fahlore were deposited after the pyrites.

A specimen (No. 229) of the enriched ore taken from the No. 3 rise of the south drive of No. 4 tunnel, consists mainly of pyrites, in which are cracks filled with iridescent bornite. When examined microscopically (Pl. XI., fig. 33) the pyrites is seen to occur mainly in spheroidal aggregates of minute crystals and spheroidal grains. They are separated by lines of black, opaque bornite. Scattered through the pyrites are a few rounded or irregular grains of quartz with some barite. The evidence of these specimens shows that the iridescent bornite is secondary, and was developed after the pyrites.

No. 231, from the open cut, is noticeable for having exceptionally large crystals of barite. The bulk consists of pyrites, which has been crushed, and fahlore which has been deposited along the lines of the cracks thus produced (Pl. XII., fig. 34).

No. 228, from the Mount Lyell mine, consists of pyrites, quartz, and galena. It is mainly a mass of pyrites, traversed by irregular cracks, due to contraction. These have been filled up with quartz, and at one place with galena. Galena occurs in black patches marked with the triangular and cuneiform cleavage planes (Pl. XII., fig. 35). The quartz and galena were deposited, almost contemporaneously, after the pyrites.

The pyritic cherts are represented by No. 214, from the No. 6 level. The rock is a band of chert, with microcrystalline granular quartz mosaic, studded with pyrites crystals. Bands of the same quartz mosaic branch off through the mass of pyrites beside it (Pl. XII., fig. 36). Running through the chert are bands of crystalline pyrites. Some larger quartz crystals, with the vertical axis parallel to the pyritic masses, occur in places between the quartz mosaic and the pyrites.

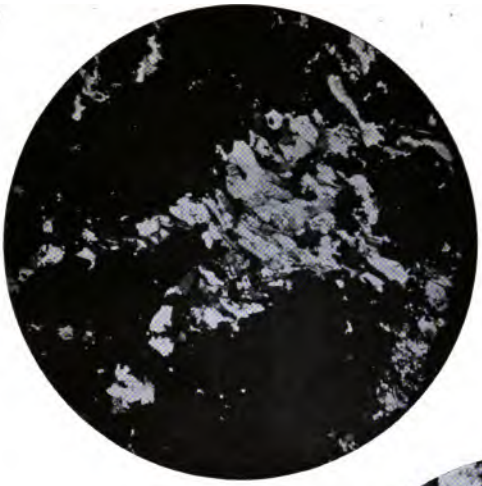


FIG. 37.—PYRITES.—With quartz veins shewing imperfect comb structure. Centre of ore body. No. 5 level. Mount Lyell Mine.

+ Nicols. × 14 dia. [No. 202].

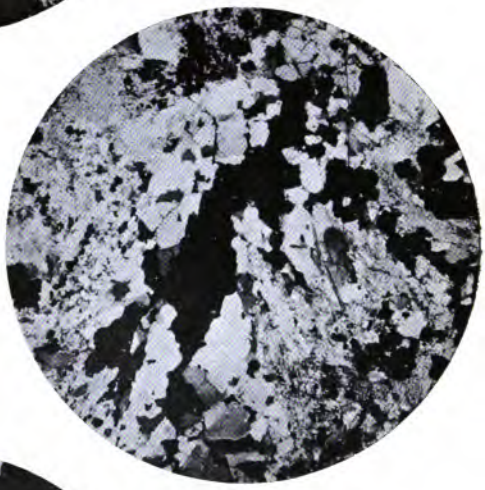


FIG. 38.—BASE OF MOUNT LYELL SCHIST.—Altered by development of bands of secondary quartz and pyrites. Crown Lyell Mine.

+ Nicols. × 14 dia. [No. 96].

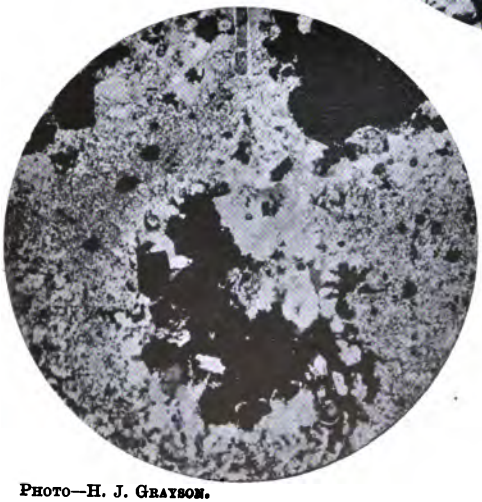


FIG. 39.—LYELL THARSIS ORE.—A pyritiferous, nodular schist.

+ Nicols. × 14 dia. [No. 41].

PHOTO—H. J. GRAYSON.

ORES OF THE
MOUNT LYELL FIELD.

A specimen (No. 202) of pyrites from the centre of the ore body is traversed by veins of quartz, which in places show comb structure, as if they had been developed secondarily in fissures in the pyrites mass (Pl. XIII., fig. 37). But the pyrites shows no trace of parallel banding, as would be expected if it had been deposited by infiltration into a fissure. The pyrites consists mainly of irregular granular spheroids, which suggest growth by a slow molecular replacement.

A laminated pyrites (No. 10) from the western end of bench No. 3A at the Mount Lyell mine is of interest, as the pyrites in mass still shows traces of the foliation of the original schists. The rock, examined microscopically, is seen to consist, in the main, of granular pyrites and pockets and curved streaks of the steel-black fahlore. The only other constituent is quartz, the grains of which occur in linear bands, the only trace apparent, under the microscope, of the banding which is so conspicuous in the rock when seen in bulk.

No. 106, from the hematite bar from the footwall of the Mount Lyell Mine, consists, in part, of quartz and hematite; chlorite occurs in granular aggregates, which represent the remnants of the schists; the rest of the rock is iron ore and quartz, which have been secondarily introduced.

The barytic hematite of the Iron Blow (No. 191) shows the association of the iron oxide and barite. The barite is mostly in well-developed crystals, and shows its typical cleavages; the iron ore occurs in granular aggregates, so arranged as to suggest their introduction molecule by molecule.

An indicator-like seam of pyrites (No. 112) from the Gormanston road consists of a band of pyrites, scattered through quartz aggregates and crushed patches of chloritic schist.

The ore from the Crown Lyell Mine (represented by No. 96) has a base of greatly altered schist (Pl. XIII., fig. 38). This rock has been altered by three distinct processes. It was no doubt originally one of the Queen River porphyrites, which was first crushed into the form of one of the Lyell schists. This foliation, and the accompanying changes, altered the rock into

a quartz mosaic, traversed by lines of white mica. The second change was the formation of bands of coarse crystalline quartz around the lines of the white mica. Finally, pyrites has been developed in loosely scattered crystals, in aggregates, and in fine dust along irregular bands through the rock. The pyrites is clearly metasomatic, for it has grown moulded on the coarse quartz. Some of the pyrites crystals in the base have sharp angles, while some of them have eaten their way into the base. According to one well-known theory, regularly developed pyrites crystals could only have been formed in a viscous base. There is no sign that the expansion of the pyrites crystals has distorted the surrounding material, as would have happened if the material had been pasty when the pyrites crystallized. The absence of such indications of disturbance leaves no doubt that the pyrites was formed metasomatically.

The Ores of the Lower Reserve Tunnel.—No. 113.—The mineral present is mainly a fine-grained granular pyrites. It is surrounded by fahlore with a bright metallic lustre, and traversed by conspicuous cleavage planes. This mineral has obviously developed later than the pyrites, and has apparently in part replaced it. The vein stuff is quartz, in some of which there are abundant crystals of white mica.

The Lyell Tharsis Ores.—No. 41 is a pyritiferous nodular schist (Pl. XIII., fig. 39). The pyrites occurs in large crystals, which have sharp angles and are sometimes twinned; some of it occurs in rounded forms, and some in aggregates or granules which are built up in crescentic or circular bands. Coarsely crystalline quartz, including flakes of white mica, occurs beside some of the pyrites. The rest of the slide is a granular quartz mosaic, also containing numerous scattered flakes of white mica. Lenticular and coarse patches of the margarodite material, with radial clusters and coarse flakes of white mica, occur in the quartz mosaic.

The rock of the footwall of the same mine is in places a red siliceous member of the conglomerate series. It is illustrated by No. 102, which the microscope shows to be a fine-grained sandstone

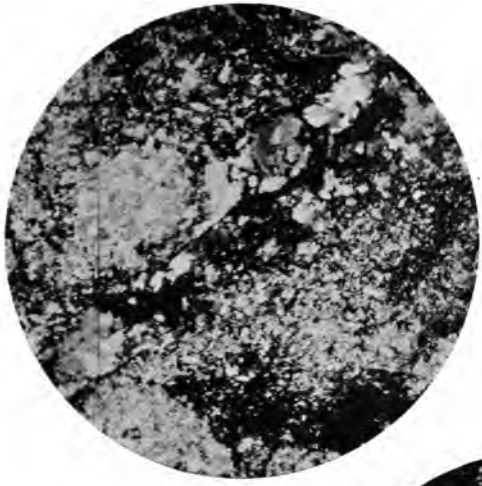


FIG. 40. — FINE-GRAINED SANDSTONE. With included grains of Lyell schist. Footwall of the Lyell Tharsis ore body.

+ Nicols. × 14 dia. [No. 102].

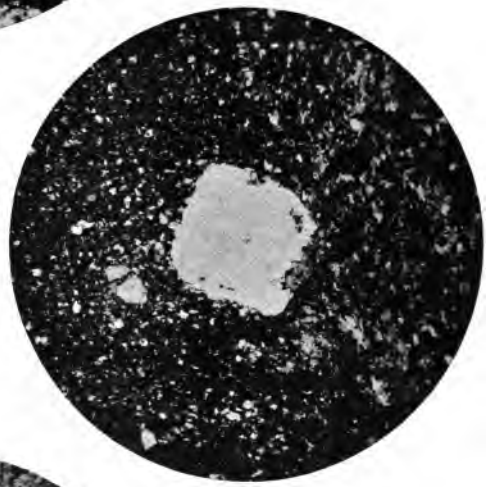


FIG. 41.—MOUNT LYELL SCHIST.—With a zonal, embayed quartz phenocryst. The rock forms the hanging wall of the Lyell Tharsis Mine.

+ Nicols. × 29 dia. [No. 103].

FIG. 42. — TYPICAL METAL-BEARING FLUX.—From the South Tharsis Mine. It is a Lyell schist, altered by the development of quartz mosaic and pyrites.

+ Nicols. × 37 dia. [No. 34].

PHOTO—H. J. GRAYSON.

ROCKS FROM THE LYELL THARSIS AND SOUTH THARSIS.

(Pl. XIV., fig. 40). Many of the quartz grains in it have been broken and brecciated, and the rest show strain-polarization effects. The fine paste between the sand grains is small in amount, and it is stained red by hematite. Some small rounded pebbles of schist occur in this conglomerate, and there are some aggregates, which were originally white mica, but are now stained by limonite and show recognizable pleochroism.

The rock on the hanging wall of this mine is a green schist, represented by specimen No. 103, which contains sufficient brassy pyrites and fahlore to serve as a metal-bearing flux. The rock consists, in the main, of irregular alternations of a quartz mosaic and of aggregates of chlorite-epidote and black grains of iron ore; these aggregates represent a diabasic modification of the original ferro-magnesian constituent. One or two of the phenocrysts are still well preserved—for example, Pl. XIV., fig. 41, which shows a quartz phenocryst that was built up zonally, and has been embayed by the ground mass. The rock is one of the Mount Lyell schists which has been rendered pyritiferous.

The South Tharsis Fluxes.—No. 34 is a specimen of the typical schist in this mine. The rock is leaden grey, and has a well-defined foliation, breaking, however, with rough, irregular surfaces. It is studded with pyrites. Examined microscopically, the rock is seen to be one of the well foliated representatives of the Mount Lyell schists. The bulk of the rock consists of foliated margarodite material, in which are developed abundant secondary groups of pyrites. Bands of coarse white mica occur along the foliation planes, and there are some lenticular patches of quartz mosaic (Pl. XIV., fig. 42).

The typical metal-bearing flux from the South Tharsis mine is represented by No. 35. The rock has the same irregularly foliated structure and leaden-grey colour as No. 34. It contains abundant pyrites and numerous eyes of quartz, which are coated with scaly leaden-grey material which has been proved in the company's laboratory to be molybdenite. Examined microscopically, the foliation is even more apparent than in the former specimen. Thin streaks of white mica are developed all through the rock,

instead of the fewer and coarser bands of the previous specimen. There are numerous angular inclusions of quartz, abundant groups of pyrites, and Pl. XV., fig. 43, shows an altered plagioclase crystal, of which the external angles are still quite sharp. The rest of the rock consists of a paste of the ordinary margarodite. The rock has the aspect, under the microscope, of a crushed, foliated quartz porphyrite. The specimen from which the slide is cut contains in places thin, flat lenticules of ore, composed of pyrites and quartz.

(D.)—SOME NOTES AND OBSERVATIONS ON THE ROCK FORMATION AND OCCURRENCE OF ORES IN THE NORTH MOUNT LYELL MINE.

By W. T. Batchelor.

(*Engineer in charge of the Mount Lyell Mining and Railway Company's Mining Operations*).

The North Mount Lyell mine is situated to the north of the parent mine, distant some 82 chains. It is located on the eastern fall of the ridge joining the two mountains, Owen and Lyell, and outcrops at a level of 1,750 feet above datum H.W.M.S.T., Strahan. It is in immediate proximity to Mount Lyell, just falling short of forming part of the flank of that mountain, and thus comprising the most northerly portion of the watershed of the Linda Valley, which has confluence with the King River some two miles and a half distant in an easterly direction. Its ores occur in close proximity to the junction of the contact rocks, which traverse the district in a slightly west of north and east of south direction. These contact rocks are made up of a series of conglomerates, quartzites, and schists. The property consists of three 10-acre sections only, which embrace in a most remarkable manner a large tract of much faulted and distorted "contact" country, along which, at irregular intervals, occur a number of separate deposits of ore, variable in shape, and following no distinct lines of deposition. The ores are essentially siliceous ones, and consist of quartz and schistose rocks containing the minerals chalcopyrite, bornite, and chalcocite. Much pyrites is also noticeable in places, mainly along the "contact" line, and floating in the adjacent schist country in the form of sporadic masses.

PHOTO—H. J. GRAYSON.

FIG. 43.—TYPICAL METAL-BEARING FLUX.—From the South Tharsis Mine, with one plagioclase crystal with well-defined outlines.

+ Nicols. × 37 dia. [No. 35].

ROCKS FROM THE LYELL THARSIS AND SOUTH THARSIS.

The typical chemical composition of the majority of the ores may be taken as follows :—

Cu	6.25 per cent.
SiO_2	72.00 per cent.
Al_2O_3	7.50 per cent.
Fe	4.50 per cent.
S	6.00 per cent.
Not determined	3.75 per cent.

with appreciable values in silver and traces of gold.

The copper contents vary between wide limits, the above representing approximately the average, compatible with economic mining and other factors. The silver is apparently associated with the copper minerals, as is determined by the increased or diminished quantities of this metal in different grades of ore.

Of the several occurrences of ore as yet outlined and prospected in the property, it is interesting to note that the deposition of the copper mineral is by no means regular—in fact, a prominent characteristic of the several working faces as exposed to view is the enriched veins or channels of almost pure bornite, varying from 3 inches up to 24 inches in thickness, enclosed within the impregnated area (locally termed " nuts "), which generally conform to the foliation of the schist country. The largest proportion of the ores is in the form of a schistose rock, impregnated with the copper minerals bornite and chalcocite, enclosed within which are small bodies of a similar impregnation in quartzite. There are also frequent bands of quartzite, carrying the minerals chalcopyrite and bornite, separating the schist from the conglomerates.

In other parts of the field, inclusive of the country adjacent to the parent and other mines, the contact rocks consist of conglomerate and schist of the usual kind, the former being of the " puddingstone " variety, and the latter generally conformable with it. Hematite of a greater or less dense nature marks the contact line throughout its sinuous course as it traverses the country; the hematite has probably been formed by metasomatic action, as a complete change is noticeable in the appearance and composition of the rocks on either side; it is most dense at the contact proper, but shows a continuous gradation into the adjoining rocks away from the fault. This alteration is noticeable in places for distances of 40 to 50 feet on either side. Generally the thickness of the hematite varies from a few inches up to a couple of feet, but, at rare intervals, " bulges "

up to 30 feet in thickness occur. It is only in a few places along the "contact" that hematite in some form or other cannot be found.

The following is the chemical composition of a sample of the densest hematite :—

Fe_2O_3	85.70 per cent.
$BaSO_4$	12.00 per cent.
Al_2O_3	2.29 per cent.
SiO_2	1.00 per cent.

As the "contact" is followed a number of transverse faults are discernible. These, until the North Lyell mine is approached, are fairly regular in form, and so far as yet proven have no economic value. The belt of country forming the "contact" rocks at a short distance to the south of the North Mount Lyell mine is, however, prominent for its irregular, shattered, and disturbed nature, as compared with other parts. The conglomerates (locally known in this part of the field as "red rock") have given place to an intensely hard, cherty quartzite, probably an alteration from the original rock brought about by chemically active percolating waters.

That these quartzites are in some instances a resulting product of chemical action through the agency of percolating waters cannot readily be disputed, as samples of rock are obtainable showing unmistakable evidence of having been originally conglomerate ; and the fact that there exists no defined line of demarcation between the two rocks, but merely a gradual merging of the one into the other, points to the conclusion that they are each part of the same series. There are, however, many other occurrences of quartzite, no doubt the result of change from the schist rock, probably due to the action of chemically active solutions and pressure; but they are usually of small extent, and detached, as compared with the "contact" quartzites alluded to above. The quartzite rock is dense, and, except for an occasional "head," is devoid of any other lines, whereas the conglomerates are generally well bedded ; both of them show marked signs of pressure, however, being cloven, crumpled, and distorted in many places. The rocks to the south generally dip at a high angle to the S.W., those to the north being inclined much more flatly to the eastward.

Throughout the leases comprising the property the "contact line" has been fairly well defined, with, as before mentioned, the ore deposits located at irregular intervals. Generally speaking it is almost invariably the case that the ore is found to exist in the depressions or troughs of the contact, although occasional instances are known at variance with this general rule.

For the better description of the above the following sketch plan of the leases is given, with the approximate position of the contact of the two rocks shown traversing the sections; also the relative position of Mount Lyell, which is situated to the north of them :—

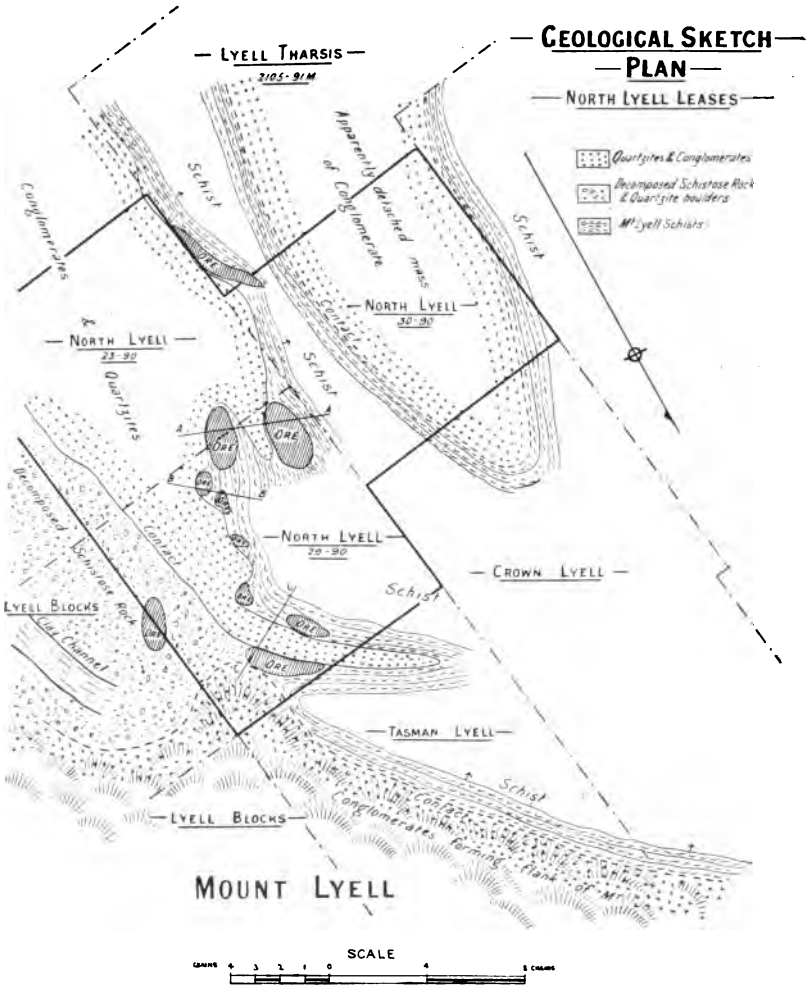


FIG. 17.

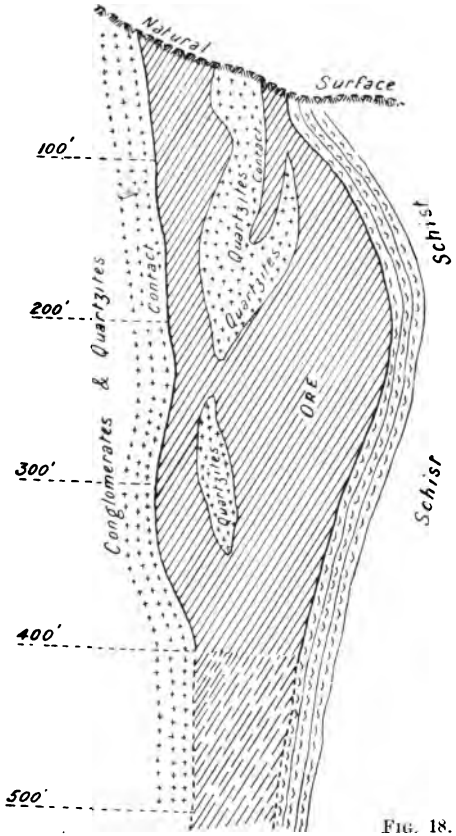
The large amount of exploratory work accomplished on the field during the last ten years points conclusively to the contact of the conglomerate and schist rocks, or, in other words, the main "fault line" traversing the country, as being the principal factor controlling the deposition of the economic metals. In no instance—other than in contiguity to this "fault line"—has any deposition taken place, except, of course, in the form of small bunches of copper ore of no value "floating" about in the adjacent schist country in proximity to the contact. The ores existing in the Mount Lyell, Lyell Tharsis, and North Mount Lyell mines are the ones referred to, each of these deposits having the conglomerates for the footwall rocks and the schists for the hanging wall rocks. There is an exception, however, in the last-named mine, in the ore occurrence known as the "eastern ore body," and also in the adjoining claim to the east, known as the Mount Lyell Blocks mine. The former consists of an irregular deposit of much broken rocks and decomposed material, principally consisting of hard, quartzitic boulders, containing a large amount of iron pyrites and a little copper.

The Mount Lyell Blocks mine is probably best known in regard to its "cupriferous clay channel," which strikes in a direction slightly west of north. It is continuous for some considerable distance, running parallel to Mount Lyell proper. It also contains sources of ore of a similar character to the quartzite and schist ores existing in the North Mount Lyell mine.

From observation it would appear as if the deposition of the ores had taken place subsequent to some of the transverse faulting, as is evidenced by the fact that these smaller dislocations intersect the impregnated areas without any apparent alteration in the peripheral walls (such as they are) of the ore occurrences. Smaller movements have, however, occurred subsequent to the deposition of the ore, but these are mostly insignificant, and appear to consist of internal strains and movements. They are not of any appreciable extent, mostly showing in the form of "slickensides."

One of the most noticeable characteristics of the ore occurrences is their peculiarity of splitting up into one or more legs, with barren material separating them. The following rough sectional sketches—which are typical, but not necessarily entirely correct—will illustrate the meaning it is intended to convey in the foregoing descriptive matter. They represent sections through the main ore occurrence, and one of the subsidiary sources of ore as indicated on sketch plan, page 111 :—

Until quite recently it had been held that some large movement had interrupted the continuity of the main ore occurrence in the North Mount Lyell mine. Naturally much speculation was indulged in to explain the problem as it presented itself at the time—viz., a supposed horizontal



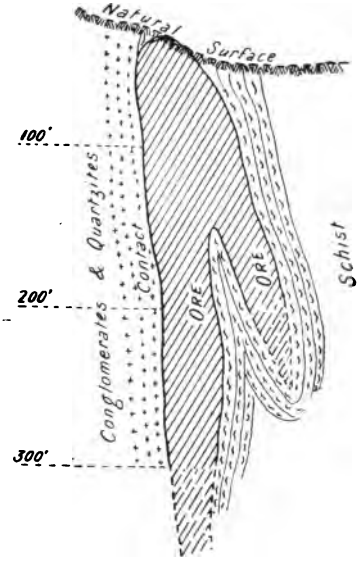


FIG. 18.

SECTION A A
(LINE A A OF FIG. 17).

SECTION B B
(LINE B B OF FIG. 17).

displacement of 200 feet in the relative positions of the main ore occurrence 110 feet apart vertically. It has been found, however, as a result of continued exploitation, that what was originally thought to be the same occurrence of ore above as that being exploited below was, in fact, for all practical purposes, a separate ore occurrence entirely, the one being a ramification of the other, but having separate "outcroppings," and consequently no displacement has been found to exist.

A characteristic feature of the ore deposits are the occasional horizontal or slightly inclined as well as vertical or highly inclined "heads" traversing the deposits, some of which are typical watercourses, as fine deposits of sand, in ripple form, have been disclosed. These heads are not confined to any one angle, and necessitate the utmost precaution being taken in exploiting the ground.

The more settled region to the north and south of the known sources of ore in and about the North Lyell mine, as is generally known, has apparently not been subjected to the severe shattering and subsequent chemical action as is visible within its prescribed area. The apparent "overthrust" of the huge mass of conglomerate into the schist area forming Mount Lyell would seem to be responsible for much of this; for its tendency would no doubt be to break up the rocks on its side immediately connected with the overthurst, and in this manner be accountable for the huge "fault plane" apparently existing, which is now filled with clays, detritus, and decomposed material.

As previously referred to, this supposed "fault line" traverses the country immediately at the base of the mountain, and running parallel to it. It has a strike slightly west of north, with a "dip" at a high angle to the S.W. The direction of the dip is, however, disputed, it being held that the rocks to the south of the known extension of the clays being inclined to the eastward, the clays must naturally follow. Be this as it may, it cannot be disputed that the clays on the northern end of the channel, for some 500 feet in depth, show a tendency to incline to the S.W. in accordance with the North Lyell schists; and as this is the only known source in respect to depth hereabouts, it should be taken in preference to data of a superficial nature only. It may, however, be found that the clays will be very irregular in their course, both horizontally and vertically.

It is held that the large "rent" in the rocks represented by the "fault plane" has, by the result of denudation and other natural causes, been gradually filled, and that the "channel of cupriferous clays" originated in this manner. On either side of the clay, more especially on the east (the side of the mountain), broken quartzite rock, intermixed with much organic matter and detritus, is prevalent, the remaining material consisting of a very soft schistose rock in a decomposed state.

The "eastern ore body," within the North Mount Lyell property, is located at a point at the north end of the "fault plane," and separates the more settled and harder rocks from the material existing on either side of the clay channel. The "ore occurrence" is quite different from any other in the mine, and is mostly made up of quartzitic boulders and decomposed matter carrying chalcopyrite and a small amount of bornite. The soft, dark decomposed matter is by far the richer in metallic contents, probably being enriched through the decomposition of the original ore.

Apart from its siliceous nature, a large amount of iron pyrites characterizes what remains of this deposit as compared with the remainder of the ore bodies found in the property, and it is locally held that the copper material has mostly been leached out.

Following is a typical analysis of the ores existing in the eastern ore body :—

Cu	.. ..	4.42 per cent.
SiO_2	.. ..	48.62 per cent.
Fe	.. ..	21.66 per cent.
$BaSO_4$	.. ..	4.00 per cent.
Al_2O_3	.. ..	4.75 per cent.
S	.. ..	16.55 per cent. (estimated)

It would appear as if this " ore body " existed on both sides of the " cape " of conglomerate jutting out into the schist area, as shown on the sketch plan on page 139, but to what depth it goes only future exploration will determine.

The eastern " leg " has been determined by a winze sunk below the 200-feet level to a depth of 100 feet. These workings show the ore to occur at this depth in a very irregular form; it mostly consists of large, quartzitic boulders, containing chalcopyrite and bornite, the latter sparingly, enclosed within a much decomposed schistose matrix, similar to that, exposed and being quarried at the surface, which has been previously referred to. The western side has not yet been prospected except for the information revealed by the shallow surface workings. The following imaginary diagram foreshadows probable development :—

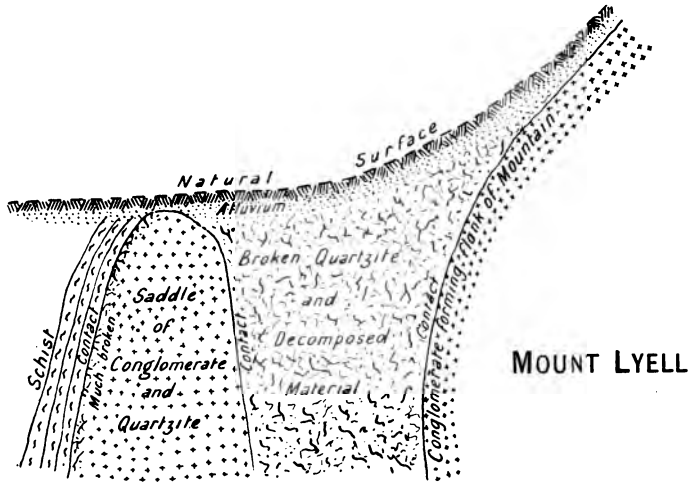


FIG. 18A.
Section across the Eastern Ore Body.
(LINE C C OF FIG. 17).

It has been suggested that the whole metal-bearing mass constituting what is known locally as the eastern workings may be somewhat out of position, chiefly owing to the fact that this portion of the country is not quite conformable with the regular contact. This contention, when considered with the "fault plane" conception, is to some extent reconcilable.

To the south of the North Mount Lyell property, and adjoining its boundaries, are located the Lyell Tharsis Company's leases, within which a lenticular occurrence of ore was discovered and worked. It consisted of the minerals bornite and chalcopyrite contained in a schistose gangue, similar to the schistose ores existing in the North Mount Lyell mine, but more talcose in appearance and feel. As before mentioned, this ore occurrence existed at the junction of the schist and conglomerate rocks, the latter forming the footwall. Its long axis was directed in a north-westerly line, the northern continuation of the ore body entering the North Mount Lyell ground, which is now being worked and exploited by surface methods only.

Latterly the developments in the North Mount Lyell mine, below the 500-feet level (reckoned from the surface), are considered as being more than favourable for the continued downward extension of the main ore occurrence at least, as, apart from the existence of payable ore at this depth, the exceedingly favourable nature of the country met with is conducive to systematic and keen exploratory work.

From the foregoing description of the North Mount Lyell mine, its ore occurrences and nature of rock formation, with brief allusion to the adjacent properties, it is hoped that some general conception may be formed of the many complex questions presented by this mine. The mine at this stage is still to a large extent unexplored, and it is impossible to forecast what the future may reveal under systematic exploration.

The notes and observations making up this narration are to a large extent disjointed, and I am afraid lack many important details that are necessary, and which should be recorded previous to a proper and reliable interpretation of the many interesting features of the mine being attempted. It will require long, patient, and intelligent observation to be brought to bear upon the subject, prior to any definite conclusions being drawn as a result of reasoning from given and correct premises.

GORMANSTON, 15*th March* 1904.

Chapter XIV.—The Genesis of the Ores.

The determination of the genesis of the Mount Lyell ores is necessary both in estimation of the future history of the field and in the determination of the most economic method of working it, The practical importance of formulating a theory as to the origin of these ores was clearly expressed by Dr. Peters. He stated—"I dislike exceedingly to indulge in any theorizing as to the formative causes of mines in a business report, but in reality the following remarks pertaining to the manner in which such beds of pyrites as that under examination are deposited, are actually as practical and as important as most any portion of my report, as unless one has a clear idea of how these great bodies of the valuable metals in combination with sulphur are originated, one cannot understand either how to work them to the best advantage, or to prospect with the best hopes of success for other similar deposits."

Upon the first discovery of the Iron Blow and its adjacent pyrites they were regarded as ordinary mineral lodes. The strike of the main deposit having been determined, it was therefore natural to expect that other deposits of copper ore should occur along the continuation of the Mount Lyell line. Great encouragement was given to this view by the discovery of the fahlbands, which certainly extend in long bands through the schists; and also by the wide distribution of alluvial gold in the field, which, it was rightly inferred, was mainly derived from the decomposition of auriferous copper-bearing pyrites.* Though the only payable gold deposits were those found on the slopes below the Mount Lyell mine, enough was found elsewhere to support the hope of the wide distribution of the copper ores. The land, both north and south of the mine,

* F. D. Power suggested that most of the gold in this field has come from the conglomerates.—Power, F. D., "Notes on the Mount Lyell District, Tasmania," Proc. Roy. Soc., Tasmania, 1891, Hobart, 1892, p. 30.

was therefore taken up by companies and searched for the continuation of the Mount Lyell lode.

Thus the South Lyell Company acquired a lease immediately to the south of the Mount Lyell mine, and sank a shaft at a point selected solely because it was on the extension of the longer axis of the Mount Lyell ore body.

Most of the early literature of the field and of the prospectuses that were issued by the various mining companies expressed the belief that the field was traversed by parallel series of copper-bearing lodes. Thus the prospectuses of the South Mount Lyell Company stated that a large proportion of the Mount Lyell lode was already proved within its boundary, and it was also proved that the whole ore body is directly entering it. The Mount Lyell Blocks Company claimed that its lode is in all probability the same as that which traverses the North Mount Lyell. The Great Southern Mount Lyell Mining Sydnicate claimed for its 300 acres "that three distinct lodes, as well as in all probability the Great Mount Lyell lode, occur across its north-eastern corner." The prospectus of the Copper Mines of Mount Lyell West Company claimed that its Kelly shaft and Razorback lode would be found to be the continuation of the North Consolidated and Extended main lode.

It was accordingly a great blow to the founders of the so-called "parasite companies" when Peters announced his famous swamp formation theory. Peters held that the pyrites had been formed by the reduction of copper sulphate solutions by the action of the organic agents in a swamp. The theory was probably suggested by the well-known deposit of iron ore at the Mesa do los Pinos, near Rio Tinto, which has unquestionably been formed by the reduction of ferrous sulphate solutions derived from the pyrites of the Rio Tinto mine. This method of origin is certainly theoretically possible. Peters' theory of the formation of the Mount Lyell ores is as follows:—

"These deposits are believed by those who have studied them most carefully, to have probably been formed before the period of mountain-building began in this country, and when the layers of

schist that are now nearly vertical were in the same horizontal position in which they were originally laid down.

"They, or neighbouring rocks, containing particles of iron pyrites carrying the valuable metals, as is exceedingly common with all varieties of sedimentary rocks. The waters flowing through the gradually decayed and dissolved pyrites, as one can see it doing to-day in most any district, and the streams flowing into some lagoon or bog-hole, came in contact with the peaty, organic acids that are always found in the waters of swamps, and that have the peculiarity of throwing down the metals out of their solutions. These metals were thus precipitated in the same state that they were originally in the rock, but in a massive, concentrated form, instead of being disseminated in minute particles throughout the rocks. In time, the slowly-growing mass of pyrites filled the swamp-hole, or more probably, a chain of holes, of great horizontal extent in comparison with their depth; the country was slowly covered with the pebbles that now form the conglomerates, or the mud that we now see in the shape of slates or schists; and the pyrite-beds were buried hundreds of feet under these newer rocks. When the mountains were elevated, these layers of rocks were tilted into their present highly sloping position, and if the upturned edges happened to break across one of these hidden deposits of pyrites, it was brought to the light of day." *

From this hypothesis it follows that such swamp deposits might occur at irregular intervals through the sedimentary series, and need not be confined along great fissure lines, due to subsequent earth movements. Other similar masses of pyrites might occur wherever the swamp conditions had been repeated during the formation of the sedimentary rock series of the district. Peters, by a hypothetical section across the country, illustrated his conclusions that the swamp deposits would be irregularly distributed, and the only chance of finding them would be where they actually outcropped at the surface. If his hypothesis had been established it might have been possible to define the limits within which these

* Peters, E. D., "Report on the Property of the Mount Lyell Mining and Railway Company Ltd.," Melbourne, 1893, pp. 6, 7.

pyritic lenses would be found. For they would occur only in the bands of rock which enclose the swamp deposits. Therefore, by tracking the outcrop of the bands of fresh water strata the possible limits of the copper ores would be directly determined.

Peters' theory, though it was adopted by many writers on the Lyell field—for example, Montgomery and MacNamara Russell—has not been confirmed by subsequent work. Further ore deposits have been found, but all those of any importance occur in association with a series of powerful faults and near the junction of the conglomerates and the schists. Hence arose the contact theory, which during recent years has been generally held upon the field.

Contact ore deposits are generally regarded as those which have been formed by the contact of igneous rocks against some different rock; such as, for example, the lead ore deposits of Leadville, due to the contact of the beds of porphyrite against beds of limestone. Thus Kemp, in his "Ore Deposits of the United States and Canada" (1900, p. 58), in his classification of ore deposits, gives as the essential feature of contact deposits that "igneous rocks always form one wall," and on p. 69 says that "this form of deposit becomes then an attendant phenomenon, or even a variety of contact metamorphism."

In this strict sense the Mount Lyell ores cannot be regarded as contact deposits, as they are not due to contact with intrusive igneous rocks. But if the term contact be used in a much wider sense, then it is not without some justification; for the great pyritic masses appear to be indirectly due to the fracturing of the schists, where they have been crushed against the harder masses of conglomerate.

The first point that must be determined is the source of the ores; and here it is natural first to turn to the fahlbands, so widely scattered through the schist series. They were regarded, both by Peters and Haber, as of primary origin, whereas Haber regarded the pyritic masses on the other hand as secondary. This view was a natural corollary to the prevalent theory of the formation of ore deposits by *lateral secretion*; for, according to Peters, the

ores in the great pyritic masses were obtained by the leaching of the disseminated pyrites from the decomposing rocks beside his swamps. Haber expressly states that "the fahlbands are to be regarded in any case as primary ore formations. On the other hand, the nature of the pyritic ore bodies indicates for them a secondary origin." * Microscopic evidence, however, clearly shows that the pyritic minerals in the schists are as truly secondary as they are in the pyritic mass. The microscopic examination, for instance, of the sections illustrated by Pl. XIII., fig. 38, 39, shows that the pyrites has been secondarily introduced into the schists, and that it is metasomatic in origin. A similar origin for the great ore masses is shown by three distinct lines of evidence. In the first place the ores are of a remarkable purity and uniformity, and, as Peters has pointed out, they are often remarkably free from extraneous matter. If the ore mass had been formed in swamps we should have expected to find layers and channels filled with ordinary mechanically-formed sediments, due to a temporary cessation of the deposition of the ores and to the occurrence of stream channels through them. We should certainly expect to find occasional rounded fragments of clastic material, and some seams of ore with more gangue. None of the microscopic sections show any fragmentary material, and the little vein stuff present appears to have been all formed by deposition from solution; and I was unable to find any clastic material in search over a considerable quantity of the ore body.

In the second place, the minerals present in the ore masses have very sharply defined crystallographic outlines, and are often built up as loose skeleton crystals, showing that they have crystallized *in situ* after the foliation of the schists. It may be suggested that the ores were formed by organic deposition and then were re-crystallized, and that this re-crystallization has destroyed the

* "Die Fahlbander sind also jedenfalls als primare Erzformation zu betrachten. Dagegen deutet die Natur der Kiesigen Erzkorper auf eine secundare Entstehung hin."—Haber, E., "Die Geschwefelten Erzvorkommen an der Westküste von Tasmania," Zeit. f. Berg-, Hütten- und Salinenwesen, vol. xlviii., 3 pt., 1900, p. 437.

evidence of their original nature. Even then we should expect a much greater variation in the composition of the ore near the margin of the pyritic mass. Montgomery logically inferred from the swamp theory that the ore mass would increase in size below, as the uniformity of the material showed that the ore then exposed was not near the margin of the pyritic mass. He reasonably expected that there would be alternations of pyrites and mechanical sediments on the margin, due to the gradual increase in the deposition of the pyrites, and later on to its decrease.

A third and more conclusive argument against the primary nature of the pyrites is the clear evidence in parts of the mine that the pyrites has been formed metasomatically by the replacement, molecule by molecule, of the original rock by pyrites.

On bench No. 3A, toward the south-eastern wall of the ore mass, the pyrites shows a well-defined banding, which is most easily explained as a pseudomorph showing the original structure of the rock. The whole of the original rock material has been removed, and replaced by pyrites, which retains the banding of the original (see pp. 103-106). The evidence of the microscopic structure is conclusive that these ore masses are to be regarded as formed metasomatically, and not as chemical deposits formed contemporaneously with the rocks in which they now occur.

The swamp theory is quite untenable when it is admitted that the rocks in which the pyrites occurs are not a continuous sequence, and that the schists and rocks beside the great ore masses have been faulted together. The pyrites masses have been deposited not only later than the deposition of the rocks, but also later than the formation of the chief faults.

That the ores in the fahlbands and the pyritic masses are of approximately the same origin was suggested by Peters, owing to their similar composition. It is well, therefore, to compare the composition of these two types of ores. The assay value of the ore at the Mount Lyell mine may be divided into three distinct types, the low grade pyrites that pays to work only as fuel, the payable pyrites, and the stoping ores. Their metallic contents are as follows:—

	LOW GRADE ORES. Between levels 4 and 5.	LOW GRADE ORES. Below level No. 5.	PAYABLE ORES.
Copper	·64 per cent.	·57 per cent.	2·92 per cent.
Silver	2·15 ozs. per ton	1·74 ozs. per ton	2.74 ozs. per ton
Gold	·048 oz. per ton	·04 oz. per ton	·097 oz. per ton

	STOPING ORES.	
Copper	10·94 per cent.	4·55 per cent.
Silver	6·23 ozs. per ton	3·58 ozs. per ton.
Gold	·022 oz. per ton	·119 oz. per ton.

The composition of the fahlband ores may be illustrated by the analysis of unusually rich ore from the Lower Reserve tunnel, and of the metal-bearing flux of the Royal Tharsis.

	LOWER RESERVE ORE.	ROYAL THARSIS FLUX.
Copper	6·96 per cent.	1·68 per cent.
Silver	·36 oz. per ton	·24 'oz. per ton.
Gold	·008 oz. per ton	·026 oz. per ton.

The relative ratios of copper, gold and silver in the metal-bearing fluxes and in the pyritic ores of the Mount Lyell mine have been re-calculated in the company's laboratory, and Mr. Sticht tells me that the Mount Lyell ores are much richer in gold and silver than the mineral in the fahlbands. This appears to me natural, if the pyritic masses have been formed by secondary concentration.

Whether the ores were formed after the rocks in which they occur (that is, are epactic, to use the term of Professor Louis*) or were formed later (the symphytic of the same author, or the hysteromorphs of Posepny), may be conclusively determined by considering their relations to the faults. It is perfectly certain that the faults of the district are later than the formation either of the schists or conglomerates. If, therefore, the ores were formed

* Phillips and Louis, "A Treatise on Ore Deposits," 1896, p. 66. *Ibid.*, p. 11.

later than the faults, then they cannot have been contemporary with the surrounding rocks. The ore deposits at the South Tharsis mine (see Fig. 12, p. 83), the North Lyell mine (see sections, Figs. 18 and 18A, pp. 113, 115), and the Mount Lyell mine are all certainly in part later than the faults.

The most striking geological feature of the Mount Lyell mineral field is its great fault system; and an examination of the distribution of the ores shows that they are in every case closely connected with the faults. These faults were not all made by the same earth movement; they were no doubt formed at different dates, extending over a considerable period of time. The deposition of the ores was probably going on simultaneously with the development of this complex fault system. Hence in one place the ores have been earlier than the faults and elsewhere they are later.

Many minor faults traverse the Mount Lyell ore body, and some of them disturb the general uniformity of its composition. Two faults were conspicuous on the floor of the open cut in January, 1903; one of them, and another on the hanging wall side of the ore body, were filled with black carbonaceous clay, formed as a fault rock. Some of this type of material (of which an analysis made in the Mount Lyell Mining and Railway Company's laboratory, is given on p. 161) contains some native copper and is rich in silver. An interesting chimney of enriched ore near the south-eastern corner of the open cut, seen on bench 3A, also owed its origin to fault action; for faults ran close beside it, in places separating the 9 per cent. ore of the enrichment from the 1 per cent. ore outside; the rich ore passed a little beyond the faults, as if the enrichment had taken place along the faults and worked from them in both directions.

These faults traverse only the pyrites. Those on the floor of the open cut were unquestionably later than the formation of the ore. The faults beside the enrichment, on the other hand, were probably earlier than at least the completion of the ore body. In the lowest level of the mine there are some interesting sections, which show that the superposition of the schists on the conglomerates occurs along lines of faulting, and that the foliation of the

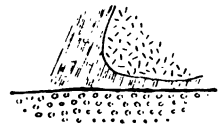


FIG. 19.

schists is cut across transversely by the conglomerates (Fig. 19). They are therefore younger, not only than the formation of the schists, but are also younger than the date at which the schists were foliated.

The two main ore masses of the Mount Lyell field both occur where masses of the schists have been nipped in the re-entering angles between great, hard blocks of conglomerate. The Mount Lyell mine has been developed in schist, which is bounded on the east by the Great Lyell Fault; to the south by the cross fault, which has thrown the Great Lyell Fault to the west; and it is bounded below by a thrust plane, which probably shifted the downward continuation of the Mount Lyell ore mass to the west, and left it isolated as the buried pyritic mass of the South Lyell Mine.

If this explanation be correct there must be two parallel faults below the Mount Lyell ore body—one at a depth of 100 feet below the No. 8 level, which has brought the conglomerates against the schist; and another about 50 feet below the same level, which cut off the original continuation of the ore body, and threw it to the west. It is possible, however, that there is only one thrust plane, which was formed before the date of the deposition of the Mount Lyell ore mass. In that case the ascending solutions which deposited the ores rose through the schists opposite the Great Lyell Fault, in the South Lyell Company's lease; on reaching the level of the thrust plane the solutions were diverted eastward over the platform formed by the thrust plane, so that they kept along the band of crushed and shattered rocks in close proximity to the Great Fault.

The intense heat generated by the formation of the Great Lyell Fault caused any waters that came from below along it to rise as hot solutions, and like most plutonic or deep-seated waters they were probably alkaline in character. They no doubt carried in solution sulphates of iron and copper and some silver and gold. These solutions, nearing the surface, had their temperatures lowered, and were subject to lighter pressures; they therefore naturally precipitated their contents along their channels. Where the solutions rose along the simple fault lines in the schists, they produced the widespread fahlbands of mineralized schist. In other places, owing to the intersection of cross faults with the Great Lyell Fault, the rocks were completely shattered and fault fissures ran in all directions through blocks of rock; in these cases mineralizing solutions would permeate the rock, removing the original constituents, molecule by molecule, and, replacing them by pyrites, formed the great ore masses. Hence the chief pyritic masses occur in every case where the schists have been completely crushed and shattered by intercrossing faults; and it is only in such positions that we can anticipate the discovery of similar ore masses. It is to be regretted that the money spent in the thousands of feet of experimental drives at the Lyell field were not devoted to prospecting the places where the chief cross faults cross the Great Lyell Fault, and in tracing the course of this fault further north and south from the Lyell field.

The contact theory of the Lyell ores cannot be dismissed without considering the relations between them and the great series of igneous rocks which lie to the west of them, both north and south of Queenstown. These igneous rocks have been described on pp. 53-59, and the evidence quoted to show that they are probably a pre-Silurian series. They cannot have been connected with the formation of the Mount Lyell ore, which must be regarded as due to tectonic and not to igneous action.

The possibility of the ores having been introduced in the form of vapours, instead of in solution, must also be considered. The metals were probably carried into the rocks in hot alkaline solutions, for the primary ores are sulphides. The gangue materials are quartz

and barite, the latter of which may have been introduced as a soluble barium sulphydrite subsequently oxidized to barium sulphate, and thus precipitated. The materials must in any case have arisen as solutions, for there is a striking absence throughout the field of volatile materials that could have ascended in vapours. There is, for example, very little arsenic. The ordinary analyses of the ores show none of it. It occurs in very small quantities in the form of enargite in some of the fahlore enrichments of the Mount Lyell mine. I saw no arsenical pyrites in the ores, but Mr. Batchelor tells me there was some at the north-western end of level No. 4 in the Mount Lyell mine. Arsenic is practically absent from the great ore masses, and is only present in the small secondary enrichments. Antimony is, of course, contained in the fahlore, and thus is present in the fahlore enrichments of the Mount Lyell mine. It also occurs in small amount in some of the fahlband ores. It is somewhat more widely distributed through the field than arsenic, but it is confined to the minerals that were last deposited. The presence of antimony is less evidence of the action of vapours than is that of arsenic. The microscope (see p. 104) shows that the fahlore occurs as strings in cracks through the pyrites or in thin skins around pyrites. The fahlore may have been due to vapour, but this is not probable, as it was introduced almost simultaneously with the quartz, which is generally deposited from solution.

Of other volatile metals, there is neither bismuth nor mercury, and there are none of the minerals of the tourmaline or topaz group, which are produced by the action of boron vapours on various felspars. The amount of zinc sulphide is much less than of galena.

There is, moreover, no evidence that the ore masses were deposited in cavities or fissures which contained free air or were reached by superficial waters. Had meteoric waters taken part in the formation of the ores we should expect the occurrence of chlorides and carbonates, which are absent except from the gossans. If the ores had been deposited in cavities we should expect the deposits would have been in layers, or, to use Posepny's term, they

would be crustified. This "crustified" structure is well developed in the pyritic ores of Roros,* in Sweden; but there is nothing of the sort shown at Mount Lyell. The lamination of the pyrites at one place on Bench No. 3 (see p. 105) is a pseudomorphic relic of the beds replaced by pyrites, and not due to the deposition of the material, layer on layer, in a fissure. Some of the quartz of the gangue shows an irregular comb structure (Pl. XIII., fig. 37), but this quartz occurs in cracks in the pyrites.

Another argument against the deposition of the pyrites in a free space, or in contact with surface waters, is the absence of sulphates (except of barium), of carbonates and metallic oxides, except where the pyrites has been secondarily altered.

These features in the great pyritic masses of Mount Lyell and the remarkable scarcity of gangue, and the general uniformity of the ore, with the concentration of the precious metals on the footwall side of the ore body, all support the view that the ores were formed by the replacement, molecule by molecule, of the pre-existing rocks. The pyrites was introduced in solutions, which permeated the country in places that had been cracked in all directions by complex earth movements.

The enrichment of the gold on the footwall side of the deposit is an ordinary case of secondary concentration. It is due to the action of descending waters, which removed the valuable metals from the higher part of the pyritic mass as it was destroyed by denudation, and then re-deposited the metals, when the soluble salts were reduced, at a greater depth.

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*Vogt, "Ueber die Kieslagerstätten vom Typus Röros, Vigsnäs, Sulitelma in Norwegen und Rammelsberg in Deutschland." Zeit. Prakt. Geol., 1894, pp. 120, 121.

Chapter XV.—The Probable Extension of the Ores in Tasmania.

Consideration of the best methods of searching for such deposits of copper ores as may still exist undiscovered in the Mount Lyell district, and in the copper belt of western Tasmania, illustrates the necessary dependence of such work on geological evidence and the practical value of theoretical questions of ore genesis. Each of the three theories of the formation of the ore deposits of Mount Lyell suggests a different method of search. According to Peters' swamp theory, an indefinite number of ore bodies might be expected to occur distributed through the schists. They might be developed especially along particular horizons, which might be recognized by a microscopic study of the schists; but without this research the ore bodies might be expected to have an apparently haphazard distribution. Dr. Peters remarked that the chances were against the discovery of his supposed swamp-formed masses of ore by mere stabbing through the schists by shafts or bores. He suggested it was better to trust to the chance discovery by prospectors of those ore bodies, of which some part outcropped on the surface, and their purchase by the Mount Lyell Mining and Railway Company, which alone could work them.

The second theory—viz., that the ores of Mount Lyell are contact products along the line between the conglomerates and schists—suggested a course of prospecting between narrow and well-defined lines. The contact line is easily discovered and it has been searched with great care and at heavy cost, but most of it has proved quite barren. As the contact theory is untenable, it is no longer justifiable to incur heavy expense in the prospecting of the contact line, except where there are other indications of the occurrence of ores.

The theory of the genesis of the copper ores advocated in this report offers more definite guidance in further prospecting. It indicates different methods of search for each of the three* distinct types of ore deposits that occur in the Mount Lyell field. The first type is that of the fahlbands. They may be expected to occur widely distributed through the schists, especially where the country has been much disturbed. They will only occur in the schists, though mineralized seams no doubt occur in the conglomerates as well. Search for these fahlbands is comparatively simple. They occur sometimes outcropping on the surface as bands of pyritous schist; in other places, where the surface has been longer exposed to the atmosphere, their existence is indicated by ironstone gossans. Both types of outcrops may be recognized on hill slopes, whence the timber and scrub have been cleared; where the surface is still hidden by vegetation the outcrops must be searched for in the creek beds or by loaming along the spurs. The search for the fahlbands involves, therefore, only the ordinary methods of prospecting for mineral lodes. The value of the fahlbands is, however, comparatively little. The largest of them pay to work as metal-bearing fluxes; but the majority are too low in grade, or too small and irregular in course to be, at present, of economic value. Some of the richer of the smaller fahlbands, however, may perhaps be profitably worked by co-operative parties, and the ore sold to the Mount Lyell Mining and Railway Company.

The second type of the Mount Lyell ore deposits is that of the great ore masses. It includes two varieties—the acid ores of North Mount Lyell and the pyritic ores of Mount Lyell. These ores have been formed where the schists have been shattered in all directions, and thus rendered permeable by mineral-bearing sulphurous solutions. The distribution of the pyritic masses and of the acid bornite ores have certain features in common, for they have both been formed where the Great Lyell Fault has been crossed by transverse movements. Accordingly the search for both types

* The third type of copper-bearing clays, as at the Mount Lyell Blocks mine, are not here considered, as I had no opportunity of studying their mode of occurrence.

of ore should follow the same lines, though the estimation of the amount of ores, and their probable depth, requires different treatment.* The search for these ore masses must be guided by recognition of the fact that they have been formed by an unusual combination of conditions; and thus it cannot be expected that they will be repeated indefinitely. Neither the acid nor basic ores have been developed in long parallel lodes, or at intervals on continuous lode lines, such as traverse so many mining fields. The hope that the ores were developed in long lodes led to the useless expenditure of great sums of money in barren prospecting, and to the foundation of many mining companies to work leases, which offered no reasonable chance of success.

Meanwhile more propitious areas have been neglected. The Mount Lyell ore deposits occur along the course of the chief geological structure line of north-western Tasmania, which I have called the Great Lyell Fault. In the company of Mr. W. T. Batchelor I traced it across the Lyell field from Mount Owen to Mount Sedgwick; and it no doubt extends considerably further in both directions. A line of mineral deposits occurs at intervals from the copper deposit of Mount Read, to the north of Mount Lyell, to those of the Darwin field, near Mount Jukes, to the south. The most propitious localities for prospecting along this line are where the Great Lyell Fault passes near masses of intrusive igneous rocks and the country has been disturbed by transverse faults. The association of the igneous rocks is necessary, as their intrusion supplied the heat which enabled the hot, ore-bearing solutions to rise into the rocks of the district. The date of the intrusion of these porphyrites was, no doubt, much earlier than the formation of the ore deposits of Mount Lyell, and the copper ores were not at once deposited in their present position. The porphyrites are not the immediate cause of the ore masses; but it was probably owing to the intrusion of these porphyrites, that the hot copper-bearing solutions were introduced into the superficial rocks. Then, long

* As I have not been underground in the North Mount Lyell mine I can only speak of it with great reserve; but the microscopic structure of its ores suggests that they are more likely to be irregular in character and distribution than the basic ores.

afterwards, these ores were concentrated into the existing ore masses. Accordingly, one cannot expect to find ore deposits wherever the rocks of Mount Lyell are intensely shattered by faults; because, unless the igneous rocks also occur in the same district, there would have been no available supply of minerals for concentration.

It is worthy of notice that, going southward from Mount Lyell along the copper belt of western Tasmania, the next area which has given promise of mineral wealth occurs where igneous rocks are intruded into the schists. This area includes Mount Huxley, Mount Jukes, and Mount Darwin. Mr. Twelvetrees has shown that in that field, granite, and probably also quartz-porphyry, have been intruded into the schists; and in the neighbourhood of these igneous rocks the schists contain many mineralized seams, which, judging from Mr. Twelvetrees' instructive account,* are similar to the fahlbands of Mount Lyell.

The second necessary condition is the occurrence of great transverse faults and disturbances, along which hot waters have been able to permeate the rocks, leach out the copper which had been introduced at the time of the intrusion of the porphyrites, and concentrate it in the shattered areas beside the Great Lyell Fault. Accordingly the search for copper ores in this part of Tasmania should be made in localities, which satisfy these two conditions—an available source of copper ores, and conditions suitable to their subsequent concentration. All such areas should be prospected in detail. In this work search should first be directed toward the discovery of considerable masses of iron gossan. Wherever huge masses of sulphide ores occur at accessible depths we may expect that the ascent of waters containing soluble copper and iron salts in solution would reach the surface, where the iron would be precipitated as either hematite or limonite. The chief copper-bearing deposits of Mount Lyell have occurred in close association with iron gossan, such as the Iron Blow and the hematite bars of North Lyell. It seems to me improbable that any

* Twelvetrees, W. H., "Report on the Mineral Districts of Mounts Huxley Jukes, and Darwin," Mines Department, Hobart, 1900, pp. 3, 4, 7.

great mass of pyrites should occur below the surface and not be marked by an ironstone gossan in the immediate neighbourhood. It is true that the pyritic ore body of the South Lyell mine had no gossan of its own; but the absence in that case is explicable, since the South Lyell ore body is probably only the downward continuation of the ore body of the Mount Lyell mine, and no doubt contributed its share to the Iron Blow.

Muir, in his paper on "The Mount Lyell Ore Deposits," rejects the idea that hematite outcrops "are the visible sign of the abundant sulphide ore mass which they overlie and cover. The fallacy of this theory has now been amply demonstrated by development and exploration work." It is no doubt true that every hematite outcrop has not necessarily a pyritic mass below, for hematite may be derived from many sources. But in the Mount Lyell field, as in Southern Spain and Tennessee, an iron gossan on the surface is an indication of some sort of ore deposit below Such gossans should be sought for in the first stage of prospecting, and should at least be carefully examined.

Even comparatively narrow gossans are worthy of search, as they may cover much wider mineral bodies below. Thus the ore mass at the Las Cabezas mine was connected to the surface by a thin seam of gossan only a quarter the width of the lode (see Fig. 27). According to Courtney,* the same thing occurs at the Tharsis mines; and the well-known underground expansion of the Rammelsberg lode (see Fig. 29) also illustrates the occasional increase of the ore body below.

The evidence of the pyritic masses of other fields also suggests that these ore bodies are not likely to be unlimited in depth, like some gold-quartz fissure veins. As the ore masses replace smashed blocks of rock, the ore masses may end off suddenly at the lower limit of the shattering, and be continued downward by a narrow channel through which the ore-bearing solutions came. Thus in

* Courtney, C. F., "Mining and Treatment of Copper Ore at Tharsis, Spain," Proc. Inst. Civ. Eng., vol. cxxv., 1896, p. 129. Sir C. Le Neve Foster, in the discussion, suggested doubts (p. 164) as to this section, but Courtney (p. 171) insisted on its accuracy.

the south of Spain the ore masses in the Rio Tinto field in places end abruptly below, as shown in Figs. 23 to 26, pp. 146-148.

The mapping of the Great Lyell Fault line across the mineral belt of north-western Tasmania is not a work which prospectors can be expected adequately to carry out. It would, I think, no doubt repay Tasmania if its Government arranged for this work to be undertaken by its Geological Survey. Private prospectors would then be in a better position to search those parts of the Great Lyell Fault line which have hitherto been insufficiently prospected. Both at Rio Tinto and Ducktown the pyritic ore masses occur at intervals across a considerable length of country, and the chances are in favour of a similar repetition in Tasmania. It is possible that the conditions which led to the formation of the ore masses of Mount Lyell may not be repeated elsewhere along the Great Lyell Fault. A careful survey of that line offers however, the best chance of the discovery of fresh copper deposits in the districts adjacent to the Mount Lyell mining field.

Part III.

PYRITIC ORE MASSES IN OTHER MINING FIELDS.

The group of ore deposits to which the Mount Lyell copper ores belong are of much interest, owing to the prolonged controversy as to their genesis. According to the long popular, and perhaps still prevalent theory, these great masses of copper ore are sedimentary beds; they are thought to have been accumulated in swamps and lakes by the action of organic matters, which reduced solutions of iron and copper sulphate that were carried into them by streams. That some ores are deposited by this process is unquestionable. It is certainly a chemical possibility for still more of them, and the lenticular shape of the masses has been regarded as an argument in favour of this view. The sedimentary origin of these ore masses of Rio Tinto, in southern Spain, has long been authoritatively advocated, and this view was greatly strengthened when Peters adopted the same explanation for the Mount Lyell ore deposits. It is, therefore, interesting to compare the Mount Lyell pyritic bodies with those of other fields.

This comparison need only include the great ore masses; for the pyritic seams of fahlbands are unquestionably secondary deposits. They are certainly not confined to certain lines of sediment, but they are developed along lines of movements and of strain, which cut obliquely across the stratification planes. The minerals in the pyritic seams have been formed by ordinary processes of replacement, and wherever they are rich enough to serve as low-grade ores, they are to be included in the category of replacement ores.

The special interest of the Mount Lyell field lies in the great pyritic masses. Their irregularly lenticular form, however, is the normal shape of ore bodies. The great majority of both ore masses and of the vein stuffs, in which ores occur, have the form of bulges or "makes," or lenticular masses. Most miners know, to

their cost, that such lens-shaped masses are usually arranged in linear series, the masses being more or less loosely connected by the track of the mother-line of the lode. The masses occur like beads loosely strung upon a string, the beads being connected by a lode track, in which the country rocks have met across the lode line. The great lenses of Mount Lyell and Rio Tinto are exceptional only by their vast size. The ores of Mount Lyell are also of interest from their richness in precious metals.

Chapter XVI.—Rio Tinto.

The Rio Tinto district lies between Huelva and the Sierra Morena, in southern Spain. The chief mines occur at Tharsis, which is 29 miles by railway to the north-north-west of the town of Huelva, and at Rio Tinto, which is about the same distance to the north-north-east (Fig. 20). Both mining fields lie to the south of the range known as the Sierra de Aracena.

The geology of this country has been described in fullest detail by Gonzalo y Tarin.* The mineral region of Huelva (Fig. 21) consists of a belt, some 20 miles in width, crossing the northern part of the province from east to west. This belt consists of Silurian and Carboniferous strata, which are traversed by many parallel intrusions of igneous rocks. The basic members of the igneous series are described as diabases, and the acid members as quartz-porphyrites and as quartzless felspar porphyrite, which occurs, *e.g.*, at the Cerro Colorado, near Rio Tinto. The quartz porphyrite at Rio Tinto is described by Gonzalo as of a bright green colour and with an "euritic paste."† Some intrusive masses of granite, syenite, and diorite occur in the Archean rocks, north of the mineral belt. The whole of the igneous rocks, according to Gonzalo y Tarin, are intrusive and of deep-seated origin, as he calls them all "hipogenica." He describes the igneous rocks of the mineral belt as surrounded by aureoles of highly altered metamorphic rocks; but in some cases, as along the northern margins of the Corte do Paite, on the Portuguese frontier, and of the Sierra del Aguila, the igneous rocks are shown on Gonzalo's map to come into direct contact with normal Silurian rocks.

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* Gonzalo y Tarin, "Descripcion Fisica, Geologica y Minera de la Provincia de Huelva," Mem. Com. Mapa Geol. España, vol. i., 1886, pp. viii., 672, 5 pl., 2 maps; vol. ii., "Descripcion Minera," 1888, pp. vii., 660, 41 pl.

† Gonzalo, *op. cit.*, vol. i., p. 643.

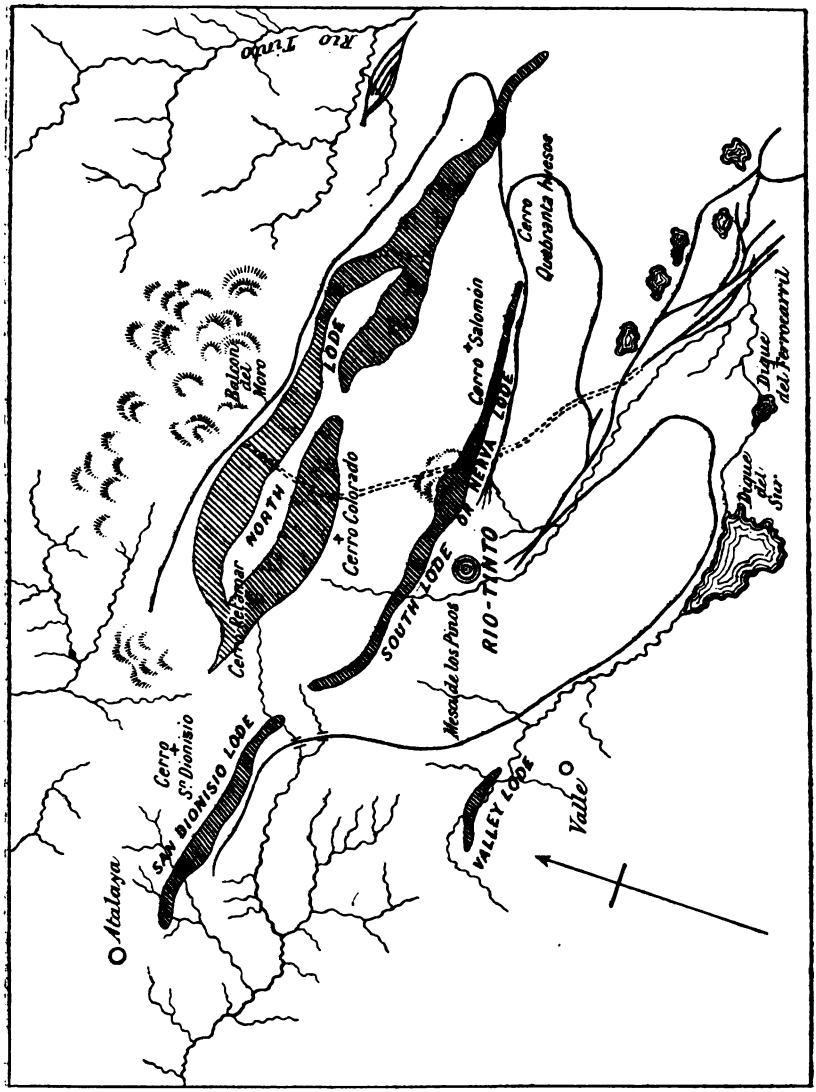

FIG. 20.

MAP OF RIO TINTO.

(Scale—1 to 30,000.)

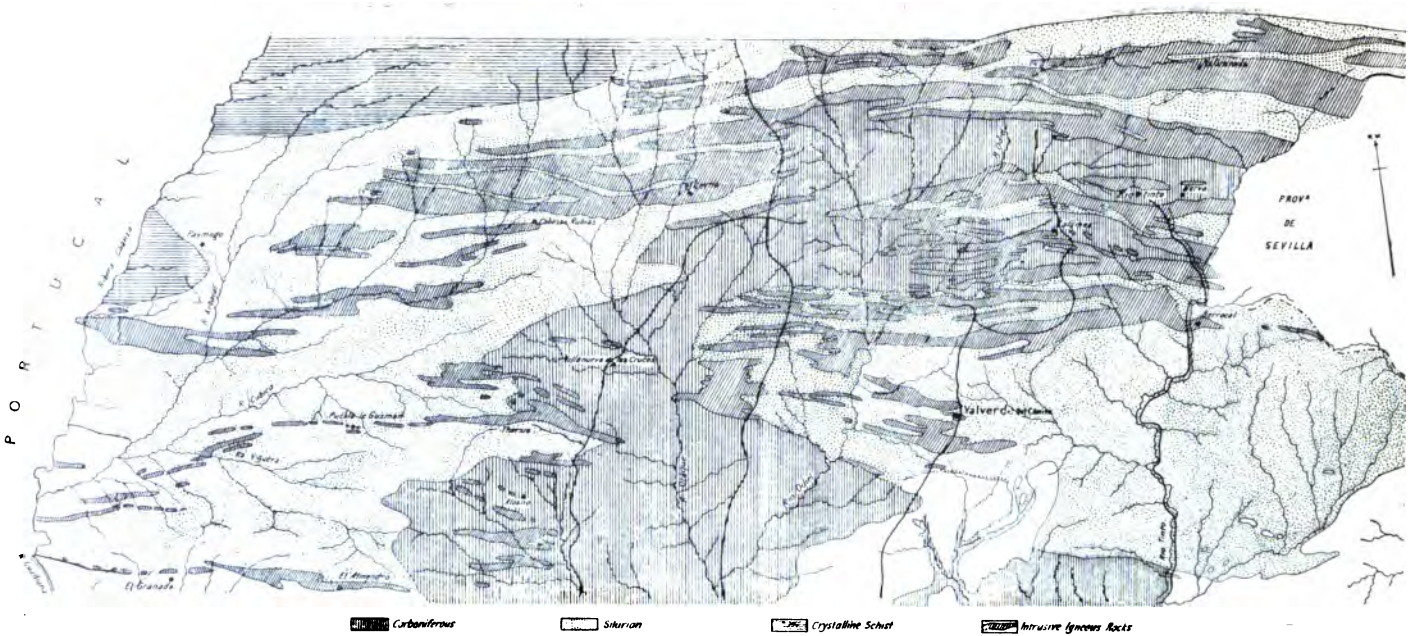

FIG. 21.

MAP OF THE MINERAL DISTRICT OF THE PROVINCE OF HUELVA.

(Scale 1 to 545,000.)

De Launay has since re-described the igneous rocks, but he practically agrees with Gonzalo. He describes the acid intrusive rocks (Gonzalo's *porfidos*) as microgranulites, passing to a petro-siliceous porphyrite.*

Professor Klockmann, however, gives a very different account of these rocks. He describes them as in part truly eruptive and containing many beds of volcanic tuffs. He says there is a complete transition from the schists to tuffs (much as there is a transition at Mount Lyell from the Mount Lyell schists to the Queen River porphyrites). "Klockmann states that a great part of what Gonzalo termed metamorphic Silurian and Culm, and of what he showed (on his map) as a regular border round the eruptive rocks, is nothing else than tuff or normal sediments mixed with ashes."†

The Silurian rocks (*i.e.*, Upper Silurian of the older nomenclature) are in the main greywackes, and various varieties of slates and phyllites, with subordinate bands of limestone and quartzite.‡

The Carboniferous rocks belong to the culm series, which is the lower part of the Carboniferous system. The typical rocks are described by Gonzalo‖ as "essentially argillaceous slates, with the layers more or less coarse, and greywackes with a compact or slaty structure." The Carboniferous rocks of Huelva are divisible into parts, of which the rocks in the lower are very similar to those of the Silurian. These rocks are also penetrated by diabase and quartz porphyrite, which have produced in them a similar metamorphism to that in the Silurian rocks.

The northern part of the Silurian strata forms a continuous band along the northern margin of the mineral district; but

* He says they "repond à des microgranulites, et ce sont en effet des microgranulites passant au porphyre pêtro-siliceux." De Launay, "Mémoire sur l'Industrie du Cuivre dans la Region d'Huelva," Ann. des Mines, ser. 8, vol. xvi., 1889, p. 466.

† Klockmann, F., "Uber die Lagerartige Natur der Kiesvorkommen des südlicher Spaniens und Portugals," Sitz. k. Preuss, Akad. Wiss., Berlin, 1894, pp. 1176, 1177.

‡ Gonzalo, *op. cit.*, vol. i., p. 397.

‖ Gonzalo, *op. cit.*, vol. i., p. 493.

further south the Silurian rocks occur in two areas of highlands, separated by Carboniferous rocks, which occupy the valley of the Oraque River. The south-eastern outcrop of Silurian rocks, which form the hilly country between Valverde and Cejo, is bounded to the north, west, and south by the Carboniferous strata.

North of the mineral belt there is a band of gneiss, crystalline schists, and other Archean rocks, which form the Sierra de Aracena. They are flanked to the north by a continuous band of Silurian rocks, the age of which is known, as it has yielded several species of *Monograptus*. This Silurian outcrop is succeeded to the north by rocks which have been determined as Cambrian, for, though they have themselves yielded no fossils, *Archæocyathus* has been found in similar beds further east, in the adjacent province of Seville.*

The pyritic deposits occur in the neighbourhood of rocks, which according to Gonzalo and De Launay are diabase and porphyrite intrusions. The ore bodies occur as lenticular masses ranging up to a mile and a half in length, and from 65 to 500 feet in width. Their number is about 50, and their bulk colossal. The quantity of ore in the various pyritic lodes has been estimated at 1,300,000,000 tons.† The ore bodies are said to occur in both the Silurian and Carboniferous strata. The mines of Tharsis, of San Domingos in Portugal, of El Carmen, Las Cabezas del Pasto, Coronada, El Tinto, &c., occur in Silurian rocks. The mines of Rio Tinto, La Zarza, La Poderosa, &c., on the other hand, are described as occurring where Carboniferous rocks have been metamorphosed by the inclusion of the quartz-porphyries. Fossils characteristic of the culm epoch, such as *Posidonomya becheri*, *P. lateralis*, *P. constricta*, and *Goniatites sphericus* are found at Rio Tinto‡ in slates closely associated with the altered rocks beside the porphyries. The evidence of the metamorphism of the Carboniferous rocks given by Gonzalo is not satisfying. It

* Gonzalo, *op. cit.*, vol. i., pp. 366, 367.

† Gonzalo, *op. cit.*, vol. ii., p. 7.

‡ Gonzalo, *op. cit.*, vol. i., p. 498.

does not wholly allay a suspicion whether the metamorphic beds may not all be of pre-Carboniferous age, and their apparent passage into the fossiliferous slates be due to the extensive faulting, which Gonzalo's work shows has taken place in the mineral belt of Huelva.

The pyritic deposits consist, in the main, of pyrite with copper pyrites, which is sometimes developed in strings, branching through the mass. Some smaller strings of copper glance (Cu_2S, the black sulphide of copper) also occur. The pyrites frequently exhibits a stratification parallel to the country rock. The ores contain from 20 to 25 dwts. of silver per ton, with a minute proportion of gold.

Courtney* gives the following as the average composition of the two chief types of ore and of the copper-bearing schist:—

ORES.	COPPER-BEARING IRON PYRITES		CUPRIFEROUS SCHIST.
	Export Ores.	Local Treatment Ores.	Local Treatment Ores.
Iron	43·1	42·8	·10
Sulphur	49·5	48·3	·15
Copper ..	2·5 to 3·0	1·5 to 2·0	1·0 to 1·25
Lead	·3	1·3	..
Zinc	·8	1·8	·05
Arsenic	·4	·7	..
Water	·5	·8	3·15
Silica	·6	·7	93·6
Oxygen and various Metals	1·20	1·1	..
	99·4	99·5	98·3
Specific gravity ..	4·5	4·5	2·25

* Courtney, C. F., "Mining and Treatment of Copper Ore at Tharsis, Spain," Proc. Inst. Civ. Eng., vol. cxxv., 1896, p. 129.

Gonzalo y Tarin gives the following determination of the quantities contained in a ton of export ore, which shows the amount of gold and silver :—*

Sulphur	477·6 kilograms.
Iron	439·9 kilograms.
Copper	36·9 kilograms.
Arsenic	8·3 kilograms.
Zinc	2·4 kilograms.
Lead	4·0 kilograms.
Cobalt	0·5 kilograms.
Bismuth	3·7 kilograms.
Lime	2·3 kilograms
Magnesia	0·7 kilograms.
Silica	19·9 kilograms.
Selenium	Traces.
Thalium	Traces.
Silver	40 grams.
Gold	892 milligrams.
Moisture	4·8 kilograms.

The course of the pyritic lodes of Huelva, or "criaderos," as they are called, is marked by bands of ironstone gossan, the relations of which to the lodes has been a matter of some controversy. The pyritic bodies are very variable in shape and geological position. Their characters can best be illustrated by the following cases :—

The western lode of Rio Tinto, or "Criadero de San Dionisio," is about 2,500 yards long, and is in places 140 yards wide. It lies along

* Gonzalo, *op. cit.*, vol. ii., pp. 318, 319.

the junction of the slates to the south and the porphyrites to the north, the latter being altered along their selvage when in contact with the lode. The ore is pyrites, with sulphides of copper, lead, and zinc, and it is traversed by veins, from 4 inches to 8 inches thick, of copper pyrites and copper glance. The form of the lode is shown in plan on Fig. 22, and by five sections across the lode. In section A B the lode is pursuing a curved course, becoming more vertical as it descends; section E F shows a considerable expansion of the lode, which in 1886 was beneath the bottom of the open cut. Another bulge of the lode occurs at the eastern end, where, however, the lode soon pinches out below, as it also does at the section G H, where a thick mass of pyrites rested with a flat base on an underlying shelf of altered porphyrites. This abrupt ending of the ore body below is shown at the end of the southern lode; but the same event happened in the middle of the northern lode, as is shown in Fig. 23. At a depth of a little over 200 feet the lode was found to rest on unaltered porphyrite, the lode being shaped in section like a flat-bottomed boat.

The Tharsis mines represent the type in which the lode is contained wholly within Silurian slates. The form of the northern lode at Tharsis is shown in Fig. 24. In the first section (A B) a horse of slates occurs between two bands of gossan, while in the second section the gossan and lode are of the same width. The pyrites lode of the mine of La Peña del Hierro, about two miles north-east of Rio Tinto, occurs on the junction between much altered slates (said by Gonzalo to be lower Carboniferous in age) and the altered porphyrites. The lode is bounded by two nearly vertical straight boundaries; the aspect of these boundaries resembles fault planes rather than lines of intrusion (Fig. 25). The sections certainly suggest that the boundaries of the pyrites are fault lines, and sections across the Rio Tinto field * show that fault action has been strongly developed there. The lustrous phyllites, which occur between the southern lode and the Culm beds, may indeed be part of the Silurian rocks brought against the culm by faults.

* Gonzalo, *op. cit.*, vol. i., pp. 500, 501.

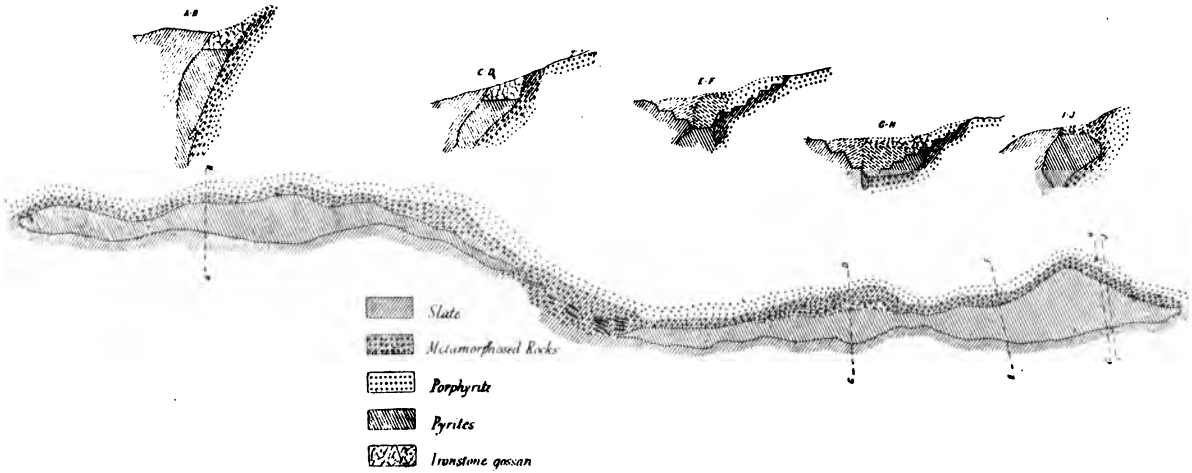

FIG. 22.

Plan and Cross Sections of the San Dionisio Lode Rio Tinto

(Scale 1 to 15,000.)

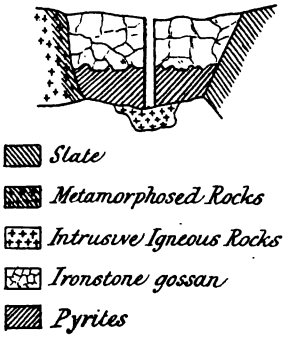

FIG. 23.

Section Across the North Lode at Rio Tinto.

(Scale—1 to 5000.)

The mine of La Chaparrita is close by that of La Peña, and represents a type in which the pyrites occurs in short vertical lenticles, at the junction of the altered porphyrites and slates (Fig. 26). Towards the south-eastern end the lode is a simple, almost vertical lenticle; following it to the north-west it increases in width and it forks at the north-western end; in one part of the lode the foot of the pyrites mass projects into the porphyrites, while above it ends in two gossans, separated by a band of slate; further north the lode increases in width to 80 feet, and it is capped by three bands of gossan separated by two blocks of schist, while at the northern end the lode has become much thinner and divided into fin-like processes, which do not quite reach the surface.

Another case of the thinning out of a pyritic mass above is afforded at Las Cabezas de los Pastos, where the lode is entirely in Silurian slates. As shown by Fig. 27, the lode suddenly contracts above and is connected to the surface by a narrow gossan. According to Courtney, the same feature occurs at Tharsis.

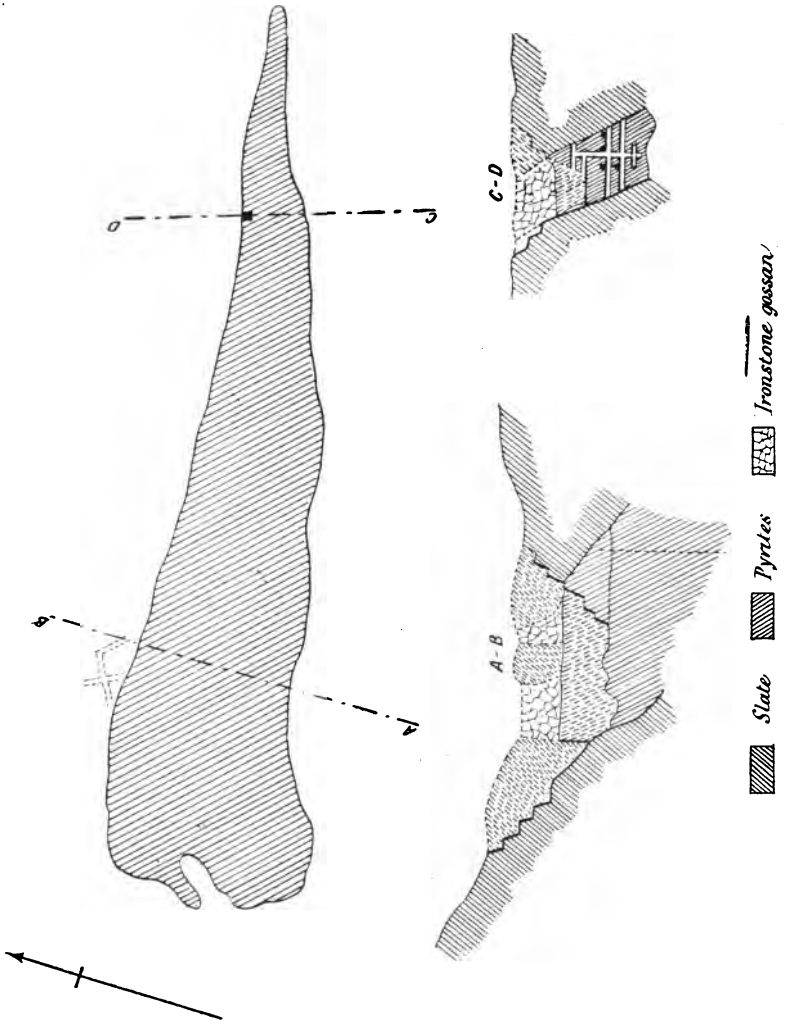

FIG. 24.

Plan of the North Lode (at No. 1 Level) at Tharsis, and Cross Sections. Along the Lines A B, C D.

(Scale—1 to 5000.)

There are two rival theories as to the origin of the Rio Tinto ores. According to Roemer* (1873 and 1876), von Groddeck (1879), and Klockmann† (1894), the ores were sedimentary and

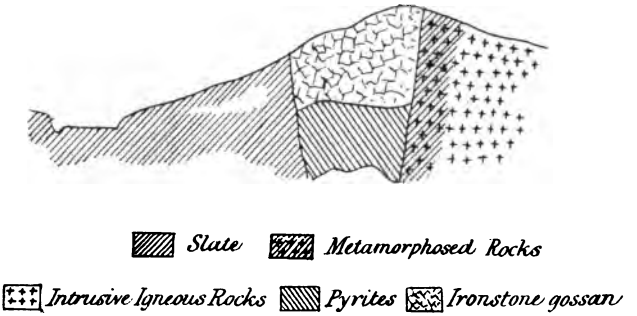

FIG. 25.

Cross Section of the Mina Peña del Hierro.

(Scale—1 to 5000.)

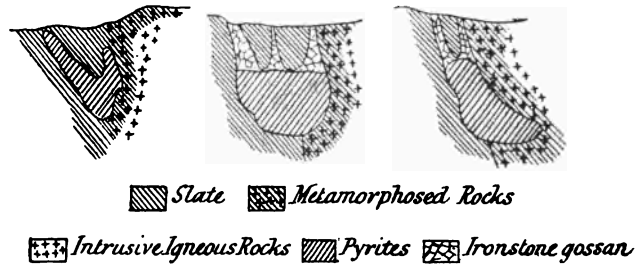

FIG. 26.

Three Cross Sections of the Mina Chaparrita.

(Scale—1 to 2000.)

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* Zeit. Deut. Geol. Ges., 1873 and 1876.

† Klockmann, "Ueber die Lagerartige Natur der Kiesvorkommen des sudlicher Spaniens und Portugals," Sitz. K. Preuss, Akad. Wiss., Berlin, 1894, pp. 1,173-1,181.

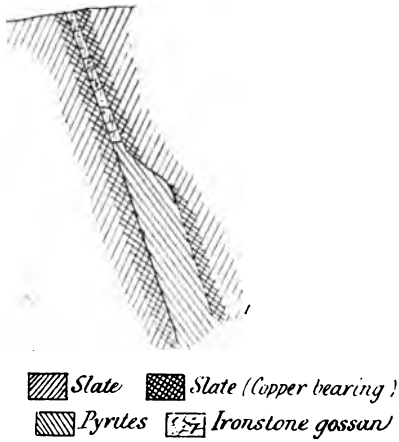


FIG. 27.

Cross Section of the Mina las Cabezas de los Pastos.

(Scale—1 to 2000.)

conformable to the surrounding slates. Gonzalo y Tarin, on the other hand, holds that the Rio Tinto ore beds are veins or lodes formed by the infiltration of minerals in solution. De Launay* (1889), Courtney† (1896), and Vogt‡ (1899) agree generally with this interpretation. The general evidence is certainly in favour of the view that these pyritic masses are metasomatic in origin and that they have been formed as replacement lodes by infiltering solutions. The trace of stratification, which led to the idea that they were bedded deposits, is probably only a pseudomorphic relic, which indicates that the pyrites has replaced sedimentary beds. The ore deposits are not normal contact deposits, because, (1) which-

* De Launay, "Memoire sur l'Industrie du Cuivre dans la Region d'Huelva," Ann. Mines, ser. 8, vol. xvi., 1889, pp. 427–515.

† Courtney, C. F., "Mining and Treatment of Copper Ore at Tharsis, Spain," Proc. Inst. Civ. Eng., vol. cxxv., 1896, pp. 126–144.

‡ Vogt, J. H. L., "Dar Huelva Kiesfield in Südspanien und dem angrenzenden Theile von Portugal," Zeit. f. Prakt. Geol., 1899, pp. 241–254.

ever authority on the field we accept, the ores were clearly formed long subsequent to the formation of the igneous rocks beside them; (2) because in other cases they occur in slates and not along a contact line; (3) and in several cases in which the ores do occur beside the igneous rocks, it appears as if the junction between the porphyrites and slates by the lodes is due to faulting (Figs. 25 and 28). In spite of the considerable literature upon the Rio Tinto field,

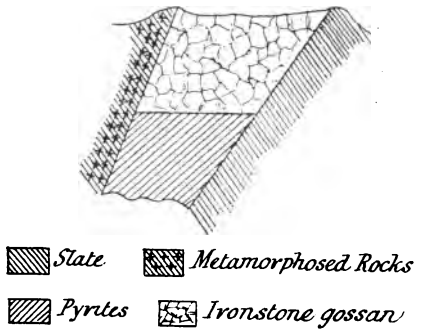


FIG. 28.

Cross Section of the Mina Lapilla.

(Scale—1 to 2000.

the mode of occurrence of its ores still requires more detailed geological and petrological description; and if Klockmann be correct in his account of the igneous rocks and of the rocks described by Gonzalo as metamorphic, the contact theory of the ores is no more tenable at Rio Tinto than it is at Mount Lyell.

Chapter XVII.—Rammelsberg.

Rammelsberg, near Goslar, in the Hartz Mountains, in Central Germany, is the next of the pyritic ore bodies to which reference need be made. The mines have been worked since the year 968, and the geological relations of the ore mass have been exceptionally well determined.

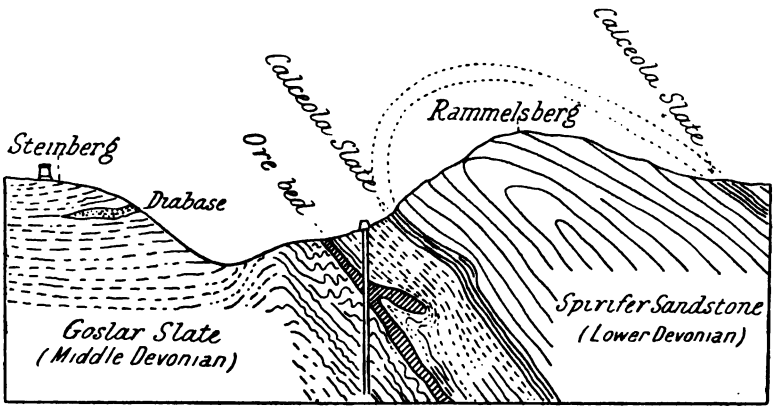
The rocks of the Rammelsberg mining field are of Devonian age. They consist, in the main, of the Goslar slates of Middle Devonian age. Rammelsberg itself is a mountain made of a great mass of Spirifera sandstone, which is of Lower Devonian age. This sandstone appears to be younger than the Middle Devonian slates, because it is brought above them by a great overfold. The ores occur in a zone which has been intensely crumpled and crushed by the earth movements, which, as at Mount Lyell, have brought the older rocks over the younger. The ores consist of aggregates of sulphides; the bulk of the ore is pyrite, mixed with copper pyrites and a little fahlore.

The ores occur in masses, which are very irregularly lenticular in shape; the greatest length of the ore is 4,000 feet and the usual thickness from 40 to 60 feet. At one place the ores are divided into two branches, and there the thickness amounts to 90 feet.

There are divergent opinions as to the origin of these ores. The ore is apparently regularly interbedded in the Goslar slates, and it appears to follow their irregularities. Hence it was naturally at first regarded as a true sedimentary deposit, a view early advanced by K. von Böhmer, and re-affirmed in recent times by Köhler, of Clausthal, and Klockmann, one of the advocates of the sedimentary origin of the Rio Tinto ores. This view has been widely accepted, and it was described in 1903 as the "most

generally accepted theory" at the meeting of the Australasian Institute of Mining Engineers at Broken Hill by Mr. H. M. Ridge.*

The Rammelsberg ore mass has, however, also been regarded as a mineral vein from the time of Delius (1770), who described ti as a stockwork, down to the recent description by Vogt.† He regards the Rammelsberg ore deposit as a true vein, formed in the shear-zone, along the fault by which the Rammelsberg rock series was inverted. The hanging wall of the ore masses is the normal Goslar slate, while the footwall is of the same rock intensely crumpled and distorted. The main ore band has a lateral offshoot (Fig. 29), which is alone a serious difficulty to the theory that



RAMMELSBERG.

FIG. 29.

the ore was formed as a sedimentary deposit. The rocks along this great fault were sheared during the earth movements, and the ores were deposited along this "shear-zone." Professor Vogt

* Trans. Austral. Inst. Min. Eng., vol. ix., 1903, p. 27.

† Vogt, J. H. L., "Ueber die Kieslagerstätten vom Typus Röros, Vigsnäs, Sulitelma in Norwegen und Rammelsberg in Deutschland," Zeit. Prakt. Geol., 1894, pp. 41–50, 117–134, 173–181, pl. ii.

regards the introduction of the ores as connected with the intrusion of the granitic rocks near Rammelsberg. He concludes—"It cannot therefore be contested that the pyritic deposits of the type of Röros and Rammelsberg, perhaps also those in Spain (?), stand genetically dependent on an acid eruptive rock."* Professor Beck, in the last edition of his "Lehre von der Erzlagerstätten" (1903, p. 492), also regarded the Rammelsberg ores as probably of later origin than the surrounding rocks, in accordance with the evidence of the microscopic study of the ores.†

The Rammelsberg ores are developed, whichever theory of their origin be accepted, along a series of overthrust faults. The ore deposits, as at Mount Lyell, are more closely connected to powerful earth movements than they are to the igneous rocks of their neighbourhood.‡

* Vogt, *op. cit.*, p. 181.

† References to the chief literature are given by Beck, "Lehre von der Erzlagerstätten," 1903, p. 492.

‡ Mr. Sticht kindly informs me that W. Wiechelt in a series of articles in recent numbers of "Berg-und Hüttenmannische Zeitung" has re-described the Rammelsberg ore body, and re-affirms its sedimentary origin; the ores, in his opinion, having been deposited as a chemical precipitate in a shallow sea.

CHAPTER XVIII.—DUCKTOWN, TENNESSEE.

The mines of Ducktown, in Tennessee, may be taken as the best representative of the American pyritic ore masses. According to Henrich,* the Ducktown basin is bounded on both sides by powerful faults. The floor of the basin is crossed by other faults, along which the Ducktown ores have been deposited. "The Ducktown ore deposits," says Henrich, "are located along fault fissures" (Henrich, *op. cit.*, p. 187).

The general geological structure of this mining field is shown by Henrich's sections. The oldest rocks of the district consist of great thicknesses of gneiss, alternating with highly contorted mica schists. A thin layer of mica schist often occurs between thick layers of gneiss, and in such cases the mica schist is crumpled into minute zig-zags and folds, owing to the sliding of the harder gneiss over the more pliable schist. The ore deposits occur upon three lines, which are roughly parallel to each other and to the strike of the adjacent rocks. The lines are from 1,200 to 1,300 yards apart, and occur along three main faults that traverse the Ducktown basin. Minor faults with the same general trend are numerous in the district, and smaller ore bodies occur along them. The ore bodies are usually lenticular in shape, and the longer axis is parallel to the strike of the country rocks. The ore bodies also dip in the same direction as the country, but usually at a steeper angle. They usually dip more than 50° from the horizontal, and some of them are almost vertical. The eastern wall of the ore body is always a fault plane, and it was,

* Henrich, C., "The Ducktown Ore Deposits and the Treatment of the Ducktown Copper Ores," Trans. Am. Inst. Min. Eng., 1895, vol. xxv., New York, 1896, pp. 175–245.

according to Henrich, always the hanging wall, but it has been in places inverted by the folding of the country. A continuous outcrop of gossan shows that the ore bodies are sometimes thousands of feet in length. Their width varies from 12 to more than 400 feet. The ores are sulphides, including pyrrhotite, marcasite, chalcopyrite, zincblende, and galena. The gossan, which occurs above the mass of the sulphide ore, is often separated from the underlying sulphide by a partly oxidized zone of rich black copper ore. Below the layer of black copper ore the sulphides are traversed by horizontal floors or partings, which extend completely across the ore body. The floors run for considerable distances along the length of the ore body, and, as they dip either north or south, two of the floors are often united.

Henrich concluded that "the places of the present ore deposits were originally occupied by (dykes of eruptive?) pyroxenic rock;" and then, during the intense earth movements connected with the Appalachian uplift, superheated solutions arose along the fault lines, deposited the gang of hornblende and garnet rocks, and replaced the original constituents of the eruptive rocks by pyrrhotite and chalcopyrite.*

Weed, on the other hand, though admitting the existence of faults beside the ore bodies, expresses doubt as to their being the cause of the ores; for the faults which he encountered were formed later than the ore masses.† No doubt when movements take place in a district containing solid blocks of minerals, the faults are most likely to be formed along the surfaces bounding such mineral masses; such secondary faults are almost certain to occur, and their existence does not disprove the primary pre-mineral faults, on which Henrich lays stress. Weed accepts the view that the Ducktown ores are replacement deposits.‡

* Henrich, *op. cit.*, pp. 218, 219.

† Weed, W. H., "Types of Copper Deposits in the Southern United States," Trans. Amer. Inst. Min. Eng., vol. xxx., 1900, p. 485.

‡ Weed, *ibid.*, p. 493.

Kemp has worked out the order of formation of the minerals in the Ducktown mines,* and his authority is in favour of the connection of the ordinary ore deposits and fault lines. He has shown that, after the mica schist and gneiss had been formed by metamorphism, a series of dislocations was formed along the lines now occupied by the lodes. Pyrrhotite and sometimes pyrites were then introduced; there were further movements which shattered those ore layers; thin lines and minute veins of chalcopyrite were then deposited in the cracks thus formed. The calcite was introduced still later; and somewhat later fresh movements formed the horizontal fissures, which have been filled with quartz, forming the "floors" found in the mines.

This description of three typical areas of lenticular pyritic masses in Spain, Germany, and America shows that they each have features similar to those of Mount Lyell, and the view that they were sedimentary in origin is untenable.

At Ducktown and Rammelsberg, as at Mount Lyell, the ore bodies certainly occur along lines of powerful earth movements. At Rio Tinto and Tharsis on the other hand, the ores are described as a contact product between porphyrites and slates.

But it is only in the case of a few of the Spanish and Portuguese pyritic masses, that they occur at the junction of slates and porphyrites; and even in those cases many of the sections given by Gonzalo y Tarin suggest that the rocks are faulted together, and that the present position of the porphyrites is not due to simple intrusion in a molten state. In other cases pyritic masses occur in the slates apart from any of the porphyrites. Moreover, where the porphyrites occur in contact with pyrites, the porphyrite is intensely altered, probably by the processes which introduced the pyrites. The suggestion, that the pyritic masses of southern Spain are due to replacement deposits along fault lines, is certainly

* Kemp, "The Ore Deposits of the United States and Canada," 3rd edition, 1900, pp. 185, 190–194, and Trans. Amer. Inst. Min. Eng., vol. xxxi., 1901, pp. 244–265.

opposed to the conclusion of the geologists who have examined the Rio Tinto field; but many of the facts they describe are more consistent with that idea than with the ordinarily accepted theory. The evidence which is available at the present time shows, however, that not one of the lenticular pyritic masses is sedimentary in origin. At Mount Lyell, Ducktown, and Rammelsberg the great pyritic ore bodies occur in association with great fault planes, up which the ores have ascended from unknown depths.

APPENDICES.

Appendix I.—Analyses of Mount Lyell Ores, Rocks, &c.

I.—The Mount Lyell Schists.

(1.)—Rock No. 216. Analysis at the Mines Department Laboratory, Melbourne, by Mr. P. G. W. Bayly, schist from the No. 1 crosscut off the north contact drive. Description of the rock is given on p. 42, and a figure on Pl. II., fig. 6.

(2.)—Typical massive schist from the North Lyell tramway. Laboratory of the Mount Lyell Mining and Railway Company, Queenstown.

(3.)—Green schist from the North Lyell tramway. Laboratory of the Mount Lyell Mining and Railway Company, Queenstown.

(4.)—Quartz schist (a crushed quartz porphyrite), Gormanston road. Laboratory of the Mount Lyell Mining and Railway Company, Queenstown.

(5.)—Green schist. Tasman and Crown Lyell Extended. Quoted from Sydney Fawns' report, published in the Queenstown *Standard*, 22nd February, 1901.

(6.)—Grey schist. Tasman and Crown Lyell Extended. Quoted from Sydney Fawns' report, published in the Queenstown *Standard*, 22nd February, 1901.

(7.)—Green nodules in schist. G. F. Beardsley.

(8.)—"Sample of country rock from the hanging wall side of the oxidized deposit from a point more than 20 feet west of the limit of the low grade deposit; it is a soft grey, almost white, schist, exhibiting a fine slaty cleavage." From the Lyell Tharsis mine. H. Stewart.

(9.)—"Schist with fine pyrophyllite veins." From the Lyell Tharsis mine. H. Stewart.

(10 and 11.)—Samples of footwall rock from the Lyell Tharsis mine. H. Stewart.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)*	(9)†	(10)†	(11)‡
SiO_2	61.05	76.0	63.6	67.4	53.4	48.0	49.4	55.25	65.5	64.29	53.50
TiO_2	.67	..	..	..	..	..	..	..	..	..	..
Al_2O_3 ..	14.24	14.0	17.6	24.6	22.67	17.46	45.1	22.44	22.51	18.91	17.51
Fe_2O_3	1.61	..	..	..	..	..	..	..	..	12.01	23.02
FeO	4.33	..	..	..	19.53	..	..	4.40	..	..	..
Fe	..	3.6	5.8	T	..	..	..	..	1.45	..	..
FeS_2	5.08	..	..	..	2.04	25.79	..	6.17	..	..	..
Cu	..	..	..	..	..	..	..	..	1.0	..	..
CuS	..	..	..	..	1.78	..	..	..	..	..	..
MnO	1.26	..	..	..	..	1.66	..	..	..	..	..
CaO	1.04	0.4	3.48	*nil*	..	..	..	*nil*	0.08	T	.37
MgO	2.09	..	..	..	..	3.4	..	1.62	T	0.76	.52
ZnS	..	..	..	..	..	1.73	..	..	..	..	..
PbS	..	..	..	..	..	1.61	..	..	..	..	..
Na_2O	1.86	1.8	1.8	3.03	..	..	..	*nil*	1.8	0.12	0.47
K_2O	1.17	1.5	3.16	2.7	..	..	..	6.97	0.3	3.67	3.54
P_2O_5	(.51)	..	..	..	..	..	..	..	..	..	..
CO_2 & H_2O (?)	..	..	..	..	..	..	..	3.57	..	..	..
H_2O, 100° ..	.23	..	..	..	..	..	..	..	0.2	..	..
Combined H_2O..	3.96	..	..	..	..	..	5.6	..	..	..	..
BaO	T	..	..	..	..	..	..	..	..	..	..
$BaSO_4$ ..	..	..	..	..	..	..	..	0.45	T	0.26	0.50
Cl	..	..	..	..	..	..	..	..	..	..	..
S	..	..	..	..	..	..	..	..	0.64	..	..
Au	..	..	..	..	..	..	..	..	..	..	..
Ag	..	..	..	..	..	..	..	..	..	..	..
Loss on ignition	..	2.3	1.30	3.03	..	..	..	..	4.0	..	..
Prob. water of constitution ..	..	..	..	..	..	..	..	..	2.5	..	..
	99.10	99.6	96.74	100.76	99.42	99.65	100.1	100.87	99.98	100.02	99.43

II.—Igneous Rocks of the Queen River Series.

(1.)—No. 186. From east of lot 3, Lynchford. A. S. Wesley.

(2.)—No. 179. Diabase porphyrite. Dyke from upper part of the East Queen River. A. S. Wesley.

(3.)—No. 174. Diabase porphyrite. Dyke from near Stubbs' Valley. A. S. Wesley.

(4.)—No. 95. Porphyrite dyke near the huts below the Crown Lyell mine. A. S. Wesley.

	(1)	(2)	(3)	(4)
SiO_2	59.8	72.7	49.5	63.2
Fe	6.8	4.2	15.4	6.6
Al_2O_3	17.84	15.6	20.06	20.58
CaO	2.6	0.36	0.3	T
MgO	3.6	0.89	1.98	1.0
S	*nil*	*nil*	3.4	*nil*
Na_2O	1.34	2.79	..	0.86
K_2O	2.67	0.79	2.07	2.35
Loss on ignition ..	2.5	1.25	7.28	3.75
	97.15	98.58	99.99	98.34

* Stewart, H., "Some Analyses of Mount Lyell Ores, Rocks, &c.," Austral. Inst. Min. Eng., vol. viii., pt. 2, Melbourne, 1902, p. 230.
† Stewart., *op. cit.*, p. 231. ‡ Stewart, *op. cit.*, p. 228

III.—Ores and Metal-bearing Fluxes.

(1.)—Typical analysis of payable ore. From the Lyell Tharsis mine.

(2.)—Royal Tharsis, lot 2.

(3.)—South Tharsis, lot 112.

(4.)—Mount Lyell ore, lot 1,459.

(5–8.)—North Lyell ores. February, 1902.

(9.)—Barytic Hematite. Mount Lyell Iron Blow.

(10.)—"Fahlore" in quartz. Probably Tennantite.

(11.)—Sample of low grade ore deposit. Lyell Tharsis.

(12.)—Bulk sample of low grade ore treated in the South Tharsis concentration mill.

	(1)*	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)†	(12)‡
$BaSO_4$ ..	1.6	..	..	3.12	..	..	..	..	12.00	..	0.45	T
FeO ..	..	..	..	..	..	..	..	..	85.7	..	11.06	..
Fe ..	3.7	9.60	7.2	40.40	11.60	4.50	2.80	3.60	..	5.05	..	..
Cu ..	4.1	2.15	1.55	2.50	13.83	6.25	25.41	28.84	..	40.00	..	..
S ..	4.3	..	..	..	14.85	6.00	9.97	3.48	..	25.26	..	..
Fe_2O_3 ..	1.39	..	..	..	..	..	..	..	..	..	3.82	1.7
FeS_2 ..	..	..	..	..	..	..	..	..	..	..	3.06	7.29 (Fe 7.0)
As ..	..	..	..	..	..	..	..	..	..	12.85	..	..
$CuFeS_2$ ..	..	..	..	..	..	..	..	..	..	..	5.67	7.83 (Cu 2.68)
CaO ..	.24	..	..	..	..	..	..	..	..	..	0.2	..
MoS ..	..	..	..	..	..	..	..	..	..	..	..	0.02
MgO ..	.21	..	..	..	..	..	..	..	..	..	0.36	0.36
K_2O ..	..	..	..	..	..	..	..	..	..	..	0.40	2.57
Na_2O ..	*nil*	..	..	..	..	..	..	..	..	..	1.52	0.72
SiO_2 ..	66.30	61.92	64.4	4.08	54.20	72.00	56.72	54.56	1.0	15.60	58.64	69.35
Al_2O_3 ..	17.72	9.37	12.64	0.15	..	7.50	..	..	2.29	..	12.52	8.5
Not det. ..	..	..	..	..	5.22	3.75	5.10	4.52	..	..	..	..
Volatile (Co_2&H_2O?) ..	..	..	..	..	..	..	..	..	..	..	.93	..
Probable water of constitut'n	..	..	..	..	..	..	..	..	..	..	1.0	..
Do. and carbonic acid ..	..	..	..	..	..	..	..	..	..	..	..	1.68
Au ..	½ dwt. per ton		..	(0.06 oz.)	..	..	..	..	..	.02 (.9 oz.)	T	..
Ag ..	15 dwt. per ton		..	.05 (2.10 oz.)	..	..	..	..	..	..	3 dwts. per ton	
	99.56	83.04	85.79	50.30	99.70	100.0	100.0	95.0	100.99	98.78	99.63	100.02
Sp. gravity	2.83	..	..	..	..	..	..	..	..	..	2.83	2.83

* Stewart, H., "Some Analyses of Mount Lyell Ores, Rocks, &c.," Austral. Inst. Min. Eng., vol. viii., part 2, Melbourne, 1902, p. 229.

† Stewart, *op. cit.*, p. 230. ‡ Stewart, *op. cit.*, p. 231.

IV.—Fault Rocks, &c.

(1.)—Carbonaceous material from footwall casing of Mount Lyell body.

(2.)—Sample from "Vugh," No. 7 workings.

	(1)	(2)
Cu	14.5 ..	..
Ag	.16 (5.9 oz.) ..	..
Fe	7.2 ..	1.5
S	9.95 ..	..
SiO_2	6.32 ..	87.6
Au	.02 (.9 oz.) ..	..
Al_2O_3	1.00 ..	10.5
Loss on ignition ..	67.5 ..	..
	106.65	99.6

V.—Queenstown Fluxes.

	(1)	(2)	(3)
Fe	2.0 ..	.40 ..	.60
Al_2O_3	3.41 ..	2.88 ..	.86
SiO_2	92.8 ..	10.92 ..	3.26
$CaCO_3$	.. ..	83.40 ..	95.10
$MgCO_3$	.. ..	3.00 ..	trace
	98.21 ..	100.60 ..	99.82

(1).—Silica from the quarries.

(2).—Grey limestone from the quarries.

(3).—Black limestone from the quarries.

Appendix II.—Composition of the Chief Minerals Found in the Mount Lyell Field.

a.—The Rock-forming Minerals.

—	—	Composition.	Formula.
Albite ...	Soda plagioclase felspar	Silicate of aluminium and sodium	Na_2O, Al_2O_3, 6 SiO_2
Andesine ...	Plagioclase intermediate between albite and anorthite	Silicate of aluminium, sodium, and calcium	Variable
Anorthite ...	Lime plagioclase felspar	Silicate of aluminium and calcium	$CaO, Al_2O_3, 2\ SiO_2$
Barite ...	Heavy spar	Sulphate of barium	$BaSO_4$
Biotite ...	A brown mica	Silicates of aluminium, magnesium, ferrous iron, and usually potassium, with some combined water	Variable
Chlorite ...	—	Silicates of aluminium, with ferrous iron, magnesium, and combined water	Variable
Damourite ...	A "hydro-mica"	Silicate of aluminium and potassium	Variable
Epidote ...	—	Hydrous silicates of aluminium, ferric iron, and calcium	H_2O, 4 CaO, 3 $(Al, Fe)_2\ O_3$, 6 SiO_2
Ferrite ...	—	Amorphous iron hydroxide	—
Labradorite ...	Lime-soda felspar	Silicates of aluminium, calcium, and sodium	Variable
Leucoxene ...	A variety of titanite formed as a decomposition product after ilmenite		—
Margarite ...	Lime-mica	Silicates of aluminium and calcium, with combined water	$H_2O, CaO, 2Al_2O_3$ $2\ SiO_2$
Margarodite ...	Crypto-crystalline to minutely crystalline mixture of the white micas muscovite, paragonite, and margarite	Variable	—
Molybdenite ...	—	Sulphide of molybdenum	MoS_2
Muscovite ...	A white potash-mica	Silicates of aluminium and potassium, with combined water	2 H_2O, K_2O, 3 Al_2O_3, 6 SiO_2
Oligoclase ...	Soda-lime felspar	Silicates of sodium and calcium	Variable
Paragonite ...	Soda-mica	Silicates of aluminium and sodium, with combined water	2 H_2O, Na_2O, 3 Al_2O_3, 6 SiO_2

a.—THE ROCK-FORMING MINERALS.—*Continued.*

—	—	Composition.	Formula
PENNINE ...	A species of chlorite	Silicates of magnesium, ferrous iron, and aluminium, with combined water	$4H_2O, 5(Mg,Fe)O, Al_2O_3, 3SiO_2$
PYROPHYLLITE*	—	Hydrous silicate of alumina	$H_2O, Al_2O_3, 4SiO_2$
QUARTZ ...	—	Silica	SiO_2
RUTILE ...	—	Dioxide of titanium	TiO_2
SERICITE ...	A variety of muscovite	—	—
TITANITE ...	Sphene	Titano-silicate of calcium	CaO, TiO_2, SiO_2

* This mineral has been quoted from the Mt. Lyell field, but the material in question is a hydrous silicate of alumina, with the formula $H_2O, Al_2O_3, 2SiO_2$ and not a bisilicate such as pyrophyllite, with the formula given above. The analysis is given as No. 7, p. 158.

b.—METALLIFEROUS MINERALS.

—	—	Composition.	Formula.
COPPER—			
Bornite ...	Erubescite; variegated copper ore	Sulphide of copper and iron	$3Cu_2S, Fe_2S_3$
Chalcocite ...	Copper glance and redruthite	Cuprous sulphide	Cu_2S
Chalcopyrite	Copper pyrites	Sulphide of copper and iron	Cu_2S, Fe_2S_3
Covellite ...	—	Cupric sulphide	CuS
Enargite ...	—	Sulpharsenate of copper	$3Cu_2S, As_2S_5$
Fahlore ...	Tetrahedrite, fahlerz, grey copper ore	Sulphantimonite of copper	$4Cu_2S, Sb_2S_3$
Tennantite ...	—	Sulpharsenite of copper	$4Cu_2S, As_2S_3$
IRON—			
Hematite ...	—	Sesquioxide of iron	Fe_2O_3
Ilmenite ...	Titaniferous iron	Oxide of iron and titanium	$(FeTi)_2O_3$
Magnetite ...	Magnetic iron ore	Ferrous and ferric oxides	FeO, Fe_2O_3
Pyrite ...	Iron pyrites	Iron disulphide	FeS_2
LEAD—			
Galena ...	—	Sulphide of lead	PbS
SILVER—			
Argentite ...	Silver glance	Sulphide of silver	Ag_2S
ZINC—			
Sphalerite	Blende; blackjack	Sulphide of zinc	ZnS

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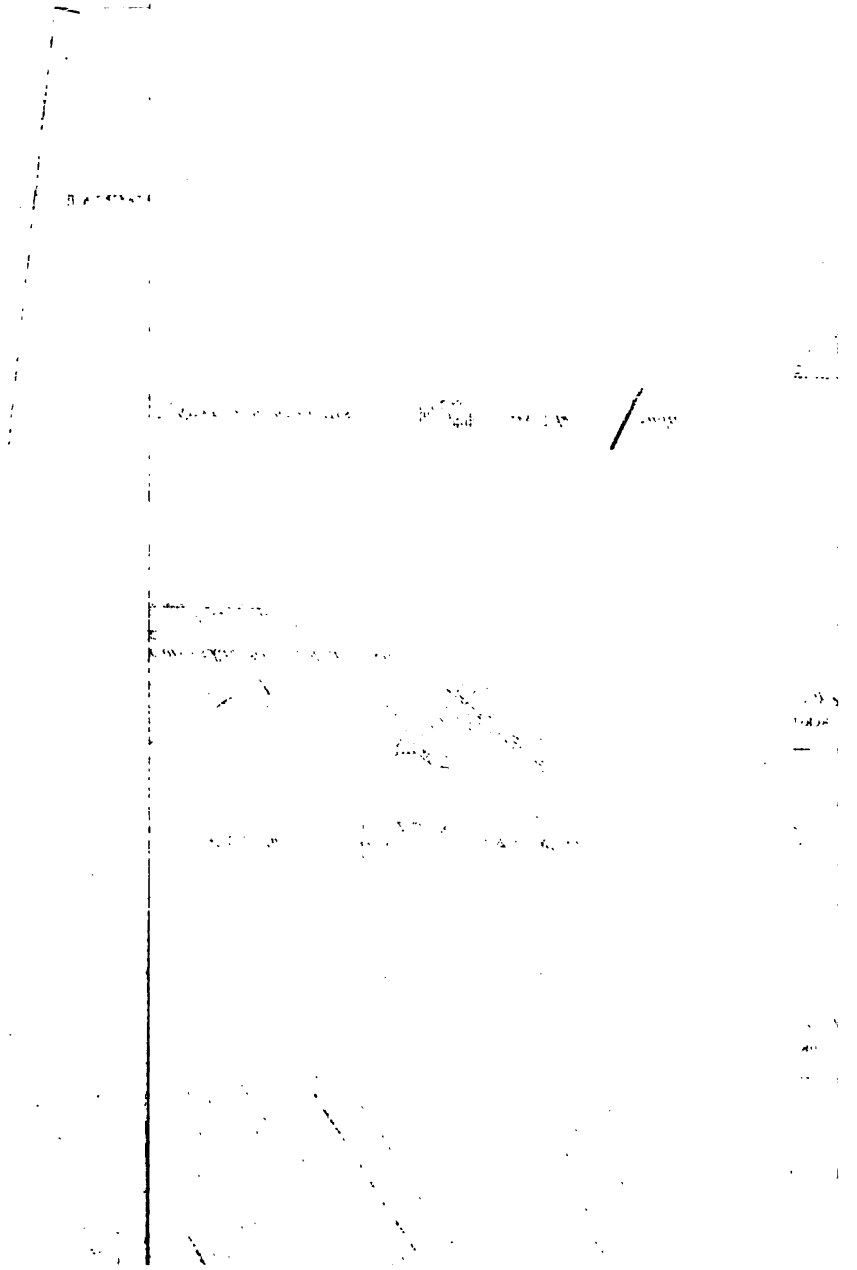


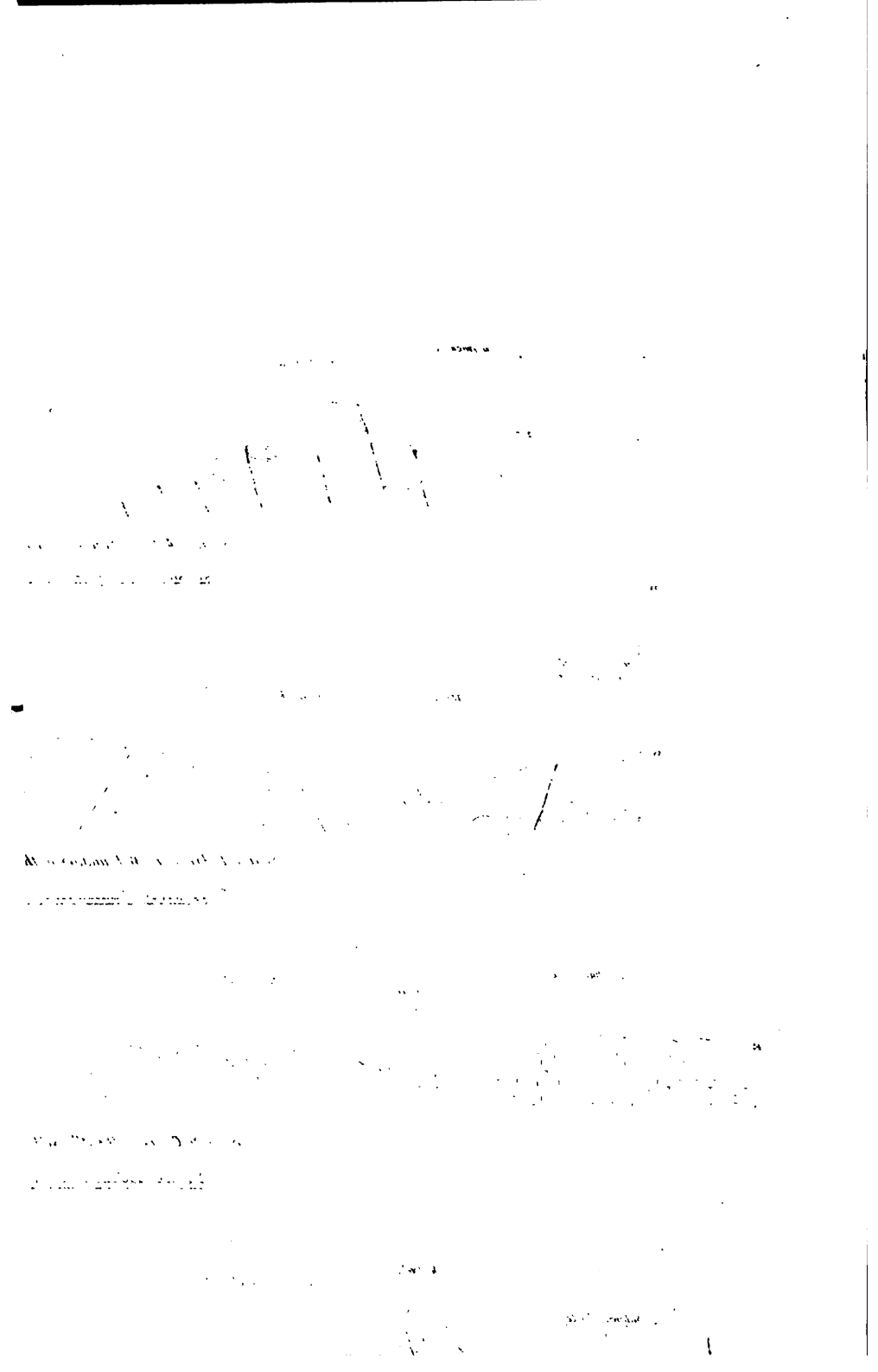
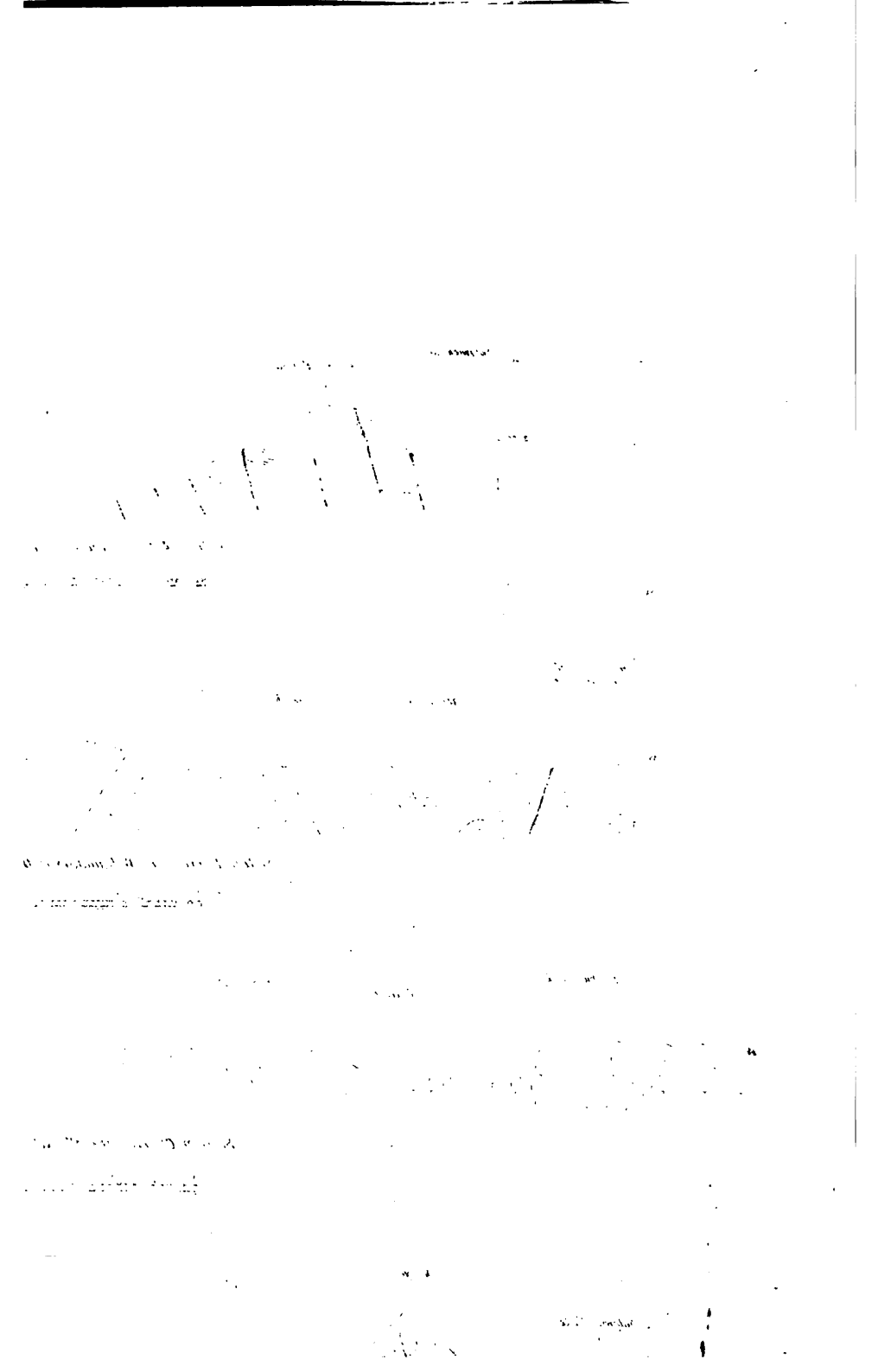


Plate XVI.



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